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Investigation of Propellant Actuated Devices for Use in Emergency Crew Escape Systems for Advanced Aerospace Vehicles

PHASE III - DESIGN STUDY

R. H. Bleikamp
E. R. Lake
D. R. McGovern
McDonnell Aircraft Corporation

TECHNICAL REPORT AFFDL-TR-65-26, PART II
April 1965

Air Force Flight Dynamics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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INVESTIGATION OF PROPELLANT ACTUATED DEVICES FOR USE IN
EMERGENCY CREW ESCAPE SYSTEMS FOR ADVANCED AEROSPACE VEHICLES

PHASE III - DESIGN STUDY

R. H. Bleikamp
E. R. Lake
D. R. McGovern

FOREWORD

The work in this report was performed by the Pyrotechnic Staff Group of the McDonnell Aircraft Corporation, St. Louis, Missouri, for the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, under Air Force Contract AF 33(615)-1292. This study is part of a continuing effort to obtain crew escape system design criteria for future high performance flight vehicles under Project No. 1362, "Crew Escape for Flight Vehicles" and Task No. 136205, "Propellant Actuated Devices (PAD) Research." Mr. M. C. Whitney of the Recovery and Crew Station Branch, Air Force Flight Dynamics Laboratory was the Program Engineer.

The work covered by this report was conducted from July 1964 through January 1965. The manuscript was released by the authors in February 1965 for publication as an RTD Technical Report.

This report represents the joint efforts of various engineering personnel throughout McDonnell Aircraft Corporation. R.H. Bleikamp was Project Study Leader. In addition to the Authors, major contributors include P. T. Gentle and C. R. Glatt.

This technical report has been revised and is approved.

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Asst. for Research and Technology
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AF Flight Dynamics Laboratory

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ABSTRACT

This report describes the results of the third and final phase of a study related to the design of PAD (Propellant Actuated Devices) for use in a separable crew escape module applicable to a lift/glide re-entry vehicle. Based on results of Phases I and II, preliminary designs have been established for each PAD as a function of component performance criteria. Prime consideration was given to successful abort at any point during the mission profile. It was found possible throughout the entire Phase III effort to evolve component designs for each PAD function without exceeding to any great extent the present state-of-the-art. As a result, the areas mentioned for future research and development are generally concerned with characterization of the more promising new explosives and propellants, and the presentation of several concepts, which, if developed, would offer secondary improvements in the overall system weight, reliability, or cost.

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ILLUSTRATIONS (Cont'd)

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1. INTRODUCTION

A number of new and challenging problems in the area of crew escape have evolved as a result of the current investigations and developments associated with advanced aerospace vehicles. Although propellant actuated devices (PAD) have played an important role in the design of past and present escape systems, there is little doubt that the complexity of future escape and recovery concepts will introduce a multitude of new PAD functions and related PAD problems. Therefore, it has been the purpose of this investigation to assess this impact of PAD on future systems by means of a design study for a crew module escape system. The separable nose escape technique, as well as the type of vehicle and its mission, were set forth as basic contractual requirements.

This volume represents the second part of a two-part final report. Although space has been allotted to a conceptual discussion of the overall system sequencing, this section is devoted primarily to Phase III, the subsystem and component design effort. Initial emphasis has been placed on general performance criteria, leading to the selection of a specific design for each PAD function. Presentation of this information has been made on the basis of seven pyrotechnic subsystems. Each device associated with a particular subsystem is discussed. In the case where a particular PAD is used in more than one subsystem, only the design criteria peculiar to the secondary application will be offered, following the initial discussion of the device.

The final portion of this report is concerned with areas amenable to future PAD research and development. For each area, a discussion of possible solutions is offered in addition to an outline of the gains to be realized by the subject R & D.

2. DESIGN STUDY (STUDY PHASE III)

2.1 Overall System Design

The preliminary vehicle design and the abort system were described in
some detail in Part I of this report. The intent of this section is to
summarize the findings reported there and present a more descriptive
picture of the abort and recovery system. Abort guidance and low-altitude
recovery system time delays are of particular significance. The results
of this effort have been used as criteria for the selection and design of
specific hardware.

2.1.1 Vehicle Physical Characteristics

The vehicle used to accomplish the normal mission is a 10,000-pound, one-
man, radiation-cooled glider having an L/D of 1.6. It is made up of two
sections. The escape capsule forms the nose of the glider and the equip-
ment module forms the aft section. The escape capsule is a 3000-pound
lifting body having aerodynamic characteristics similar to ASSET, a USAF
aerothermodynamic research vehicle designed and built by McDonnell. The
layout of the capsule, as developed during this study, is shown in Figure
1. A detailed description of the overall capsule configuration and aero-
dynamic characteristics is given in Part I of this report. The basis for
the locations and configurations of various components shown will become
evident in ensuing sections of this volume. The equipment module plan-
form is a continuation of the delta wing planform of the escape capsule,
while the fuselage maintains a constant cross section equal to the escape
capsule cross section at the interface. The complete glider is shown in
Figure 2. No consideration has been given to control surfaces, although
it is recognized that both longitudinal and lateral stability and control
surfaces would be required.

The glider is vertically launched into a 200-nautical-mile orbit for a
mission of several days' duration by a two-stage launch vehicle. The
velocity/altitude profile of the mission is shown in Figure 3. Abort
conditions considered in the design of the escape and recovery system
are shown along the mission profile.

2.1.2 Escape and Recovery Systems

Investigation of system requirements to provide safe escape and recovery
from all mission phases following detection of a booster/glider malfunc-
tion has evolved the need for four basic rocket systems. Recovery of the
escape capsule following the various escape maneuvers considered has
indicated the need for two parachutes.

The characteristics for the rockets needed are summarized in Table 1.
An escape tower is provided for off-the-pad and early boost phase aborts
to achieve the axial separation between the escape capsule and the
booster/glider which would be required to escape the blast overpressure

Drogue Suspension Release

Windshield Cover Release Actuator

Impact Bag Compartment

Tower Jettison Rocket

Flotation Bag Compartment

Flotation Bag

Landing Abort Escape Rocket

$\lambda - \lambda$

Windshield C

Windshield Cover Remover

Main Chute Compartment

Flotation Bag Pressurization Tank

Windshield Cover
Release Mechanism

Flotation Bag

Escape Tower Separation Nuts

Pad Abort Escape Rocket

Forward Impact Bag

Press
Valve

Impact Bag Pr

FIGURE 1   ESCAPE CAPSULE LAYOUT

3

Drogue Suspension Release

Windshield Cover Release Actuator

...act Bag Compartment

...r Jettison Rocket

Flotation Bag Compartment

Flotation Bag

Impact Bag Compartment

Aft Impact Bag

Landing Abort Escape Rocket

A-A

Drogue Chute Mortar

Entrance Hatch

Windshield Cover

Windshield Cover Remover

Main Chute Compartment

Windshield Cover
Release Mechanism

Flotation Bag Pressurization Tank

Flotation Bag

...pe Tower Separation Nuts

Command Module

Pressurized Cabin   Guillotine Cable Cutter

Separation Clearance Line
(Two Retro's Firing)

Insulation (Removed by
Drogue Chute

Retro Rockets

Posigrade Rockets

Forward Impact Bag

Pressurization
Valves

Aft Impact Bag

Nose Landing Gear Actuator

Impact Bag Pressurization Tank

Main Chute Catapult

2

CAPSULE LAYOUT

Impact Bag Compartment

Aft Impact Bag

Command Module

ortar

Pressurized Cabin   Guillotine Cable Cutters

Separation Clearance Line
(Two Retro's Firing)

Insulation (Removed by
Drogue Chute

Retro Rockets

Posigrade Rockets

Aft Impact Bag

Nose Landing Gear Actuator

Main Chute Catapult

Drogue Chute Repositioning Release

Pressurized Cabin

Explosive Bolt-Capsule Separation

3

FIGURE 2 GLIDER CONFIGURATION
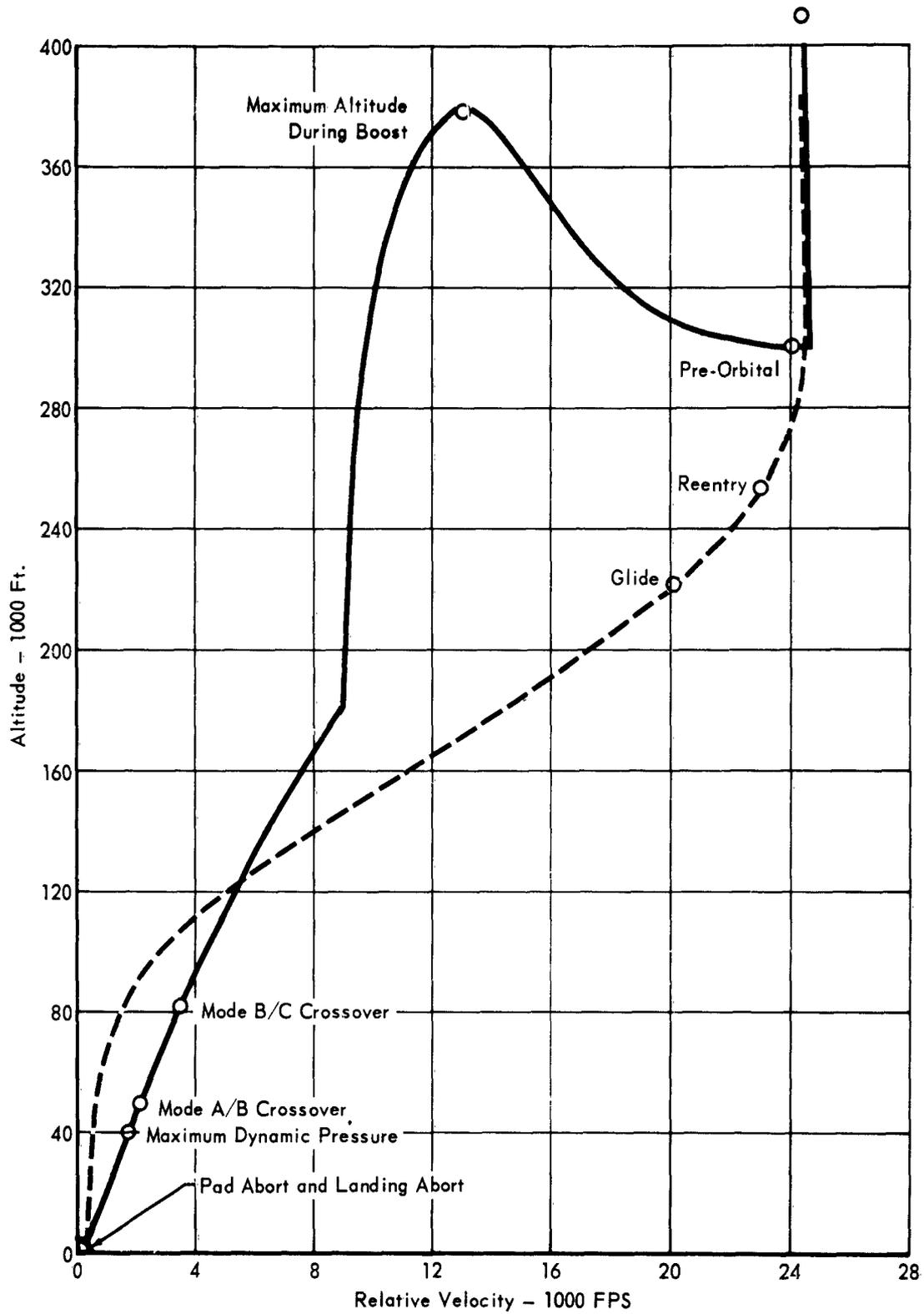
FIGURE 3 — MISSION PROFILE AND ABORT CONDITIONS

TABLE 1

ROCKET MOTORS - "PAD" STUDY VEHICLE

Motor	No. Req.	Ave.* Thrust	Burning Time	Total* Impulse	Specific Impulse	Propellant* Weight	Total* Weight	Length Overall	Principal Diameter
Pad Escape	1	50,000#	1.0 sec	50,000 lb-sec	225 sec	222#	330#	70.3 in	15.1 in
Tower Jettison	1	785#	1.4 sec	1,100 lb-sec	200 sec	5.5#	17.3#	16.8 in	4.8 in
Posigrade	3	345#	1.0 sec	345 lb-sec	224 sec	1.54#	3.8#	14.9 in	2.8 in
Retro	3	3,000#	5.0 sec	15,000 lb-sec	225 sec	62#	74#	21.8 in	13.4 in
Landing Abort	2	16,500#	.67 sec	11.000 lb-sec	220 sec	50.0#	75.0#	28.0 in	8.2 in

* Per rocket

TABLE 2

RECOVERY PARACHUTES-PAD VEHICLE

	Drogue	Main
Design Recovery Weight - lbs	3,000	3,000
Parachute Type	Hemisflow	Ringsail
Diameter (D_O) - Ft	7.5	69
Percent Reefing - percent	None	11.5
Drag. Coeff. (C_D)	.4	.75
Drag Area (C_DS)	17.5	2,800
Normal Deployment Conditions		
Deployment Altitude - Ft	70,000	15,000
Deployment Mach No.	1.1	.28
Normal q - psf	90	65
Design q - psf (Terminal)	220	220
Opening Shock Load - g's	2.3	4.5
Disreef Shock Load - g's	--	3
Volume - in.^{3}	350	5,770
Weight - Lbs	25	75

From emergency power supply

(P/G)

Abort switch

Mechanical
Hot gas
Electrical
SMDC

(P/G) Normal pilot/ground control
(E) Emergency pilot/ground control
(B) Abort power buss

Pyrotechnic switch (no delay)

T.D. Time delay switch (time in seconds)

Barostat (closed below altitude indicated)

1st stage booster shutdown

2nd stage booster shutdown

Abort power buss (B)

Emergency environmental control system

Reaction control system

Escape capsule severance system

Mode selector switch

| A | B | C | D | E | F | G | H |

Posigrade rockets

(P/G)

From glide vehicle power supply

Tower escape rocket

T.D. 1.5

(B)

Interrupt option

(P/G)

T.D. 1.0

(B)

Tower jettison release and rocket

Mode selector switch

| C | D | E | All |

Roll control yaw control

Inertial measuring unit

T.D. (B)

T.D.

(B)

Com͟ ͟er Vγh

Reentry attitude bias

Retro attitude bias

Guidance and control system

FIG. 4   ESCAPE AND RECOVERY SYSTEM SCHEMATIC

Mechanical

Hot gas

Electrical

SMDC

(P/G) Normal pilot/ground control

(E) Emergency pilot/ground control

(B) Abort power buss

Pyrotechnic switch (no delay)

T.D. ** Time delay switch (time in seconds)

Barostat (closed below altitude indicated)

Posigrade rockets

Mode selector switch

A B C D E F | G | H

T.D. 9.5

Landing gear retract

T.D. 15

Windshield cover release and removal

70K

INTERVALOMETER .5 5 15

Drogue mortar

Drogue reposition

15K

T.D. .5

R

T.D. 10 sec. Pyro delay

Drogue release

Apex line cutter

T.D. 1.5

Landing abort rocket

Interrupt option (P/G)

Inertial measuring unit

Computer Vγh

T.D. .3

Main chute catapult

Main chute deploy

Disreef 2.5 sec.

Impact switch

Main chute disconnect

Arming switch

Impact attenuation system

Flotation system

INTERVALOMETER 0 5 10 16

Retro #1

Retro #2

Retro #3

ude
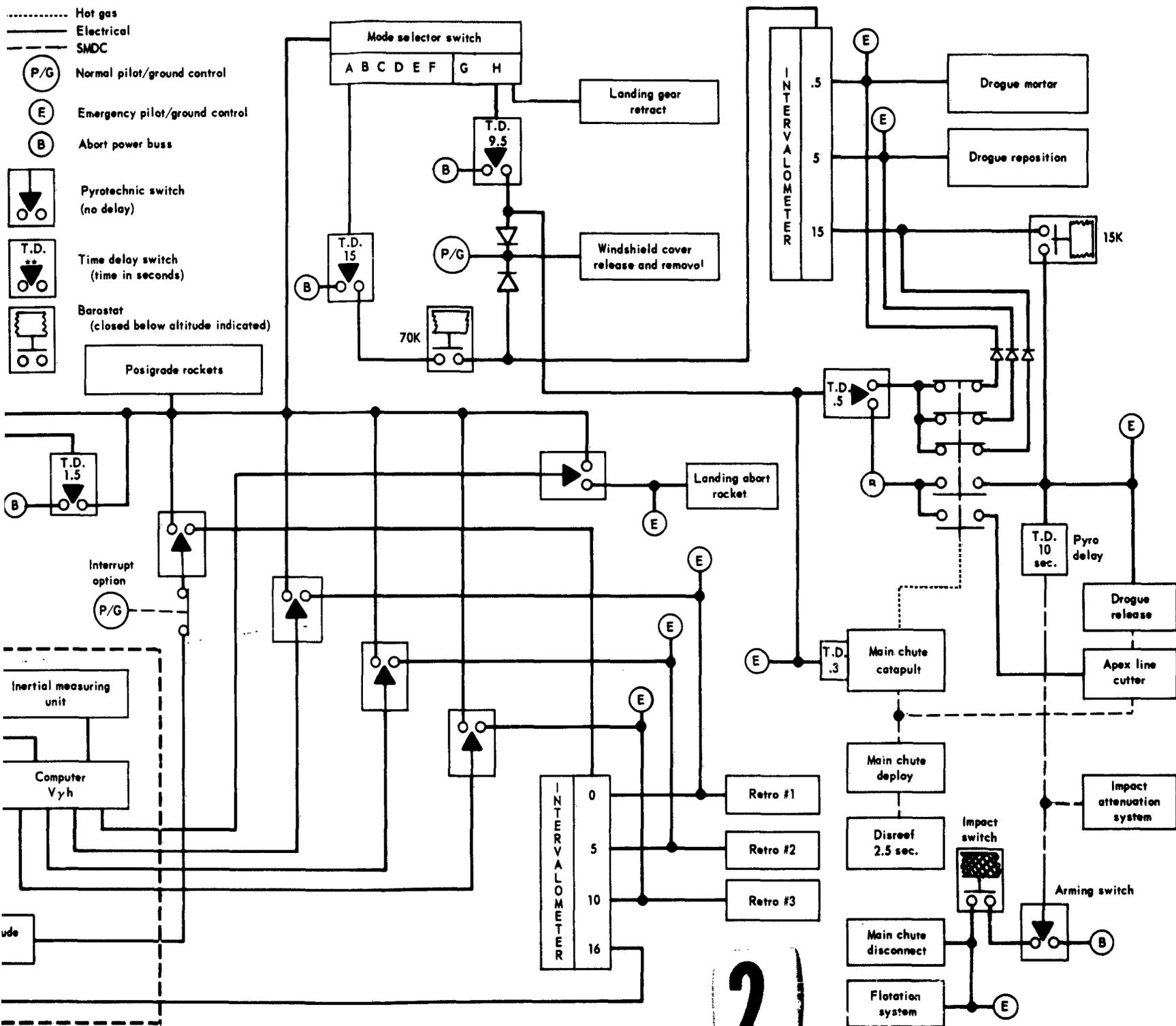
EM SCHEMATIC

2

and fireball associated with a booster malfunction. Three small separation rockets provide the necessary impulse for separation when atmospheric and gravitational considerations are not critical. Retrograde rockets are necessary to deorbit following an orbital or near-orbital abort. Landing abort rockets, together with the lifting characteristics of the escape capsule, provide the altitude gain necessary to allow time for parachute deployment when the glider is in the terminal phases of the mission. All rockets are burned during or following an abort to establish a consistent center of gravity, and to eliminate "live" rockets for maximum safety in landing. In some cases the supplemental burning enhances the separation characteristics, as in the case of retrograde burning following an off-the-pad abort. The rockets are sequenced to take greatest advantage of supplemental burning.

A landing parachute in conjunction with impact bags is provided for re-covery of the escape capsule. Because of the inherent instability of the escape capsule in the subsonic/transonic flight region, and because of excessive shock load which would be encountered by deployment of the land-ing parachute at high altitudes, a small drogue parachute is provided to stabilize the escape capsule during the relatively long free fall follow-ing a high-altitude abort. The drogue parachute also is used to extract the landing parachute following a high-altitude abort although a landing parachute catapult is provided for time-critical low-altitude aborts. The parachute characteristics are shown in Table 2.

2.1.3 Abort Modes

The escape and recovery systems described in the preceding paragraphs are sequenced by abort mode logic to achieve safe recovery of the escape cap-sule from any phase of the mission. Figure 4 presents the integrated escape and recovery schematic. Preliminary investigation indicated that a maximum of eight combinations of escape and recovery techniques or abort modes would be required. Subsequent analysis has shown that only seven of these are necessary because the low-altitude glide and landing aborts can use the same sequence. Pictorial representation of the seven abort modes are presented in Figures 5 through 11. The required sequenc-ing is indicated on each figure for that abort mode.

Because of the Work Statement requirement that the system be automatic, many aspects of abort mode selection are governed by the guidance and control computer. Thus, the mode selection can be reduced to three posi-tions. The launch position includes modes A and B which have the same escape and recovery sequences but differ in the method of initiation of the recovery sequences. Modes C, D, E, and F are differentiated within the guidance and control system, so a single manual selection is provided. Identical abort and recovery sequencing in the low-altitude glide and landing region allows the use of a third and final selector position.

Basically, the span of flight parameters within which the spacecraft can be operated is determined by the boundaries imposed by the velocity,
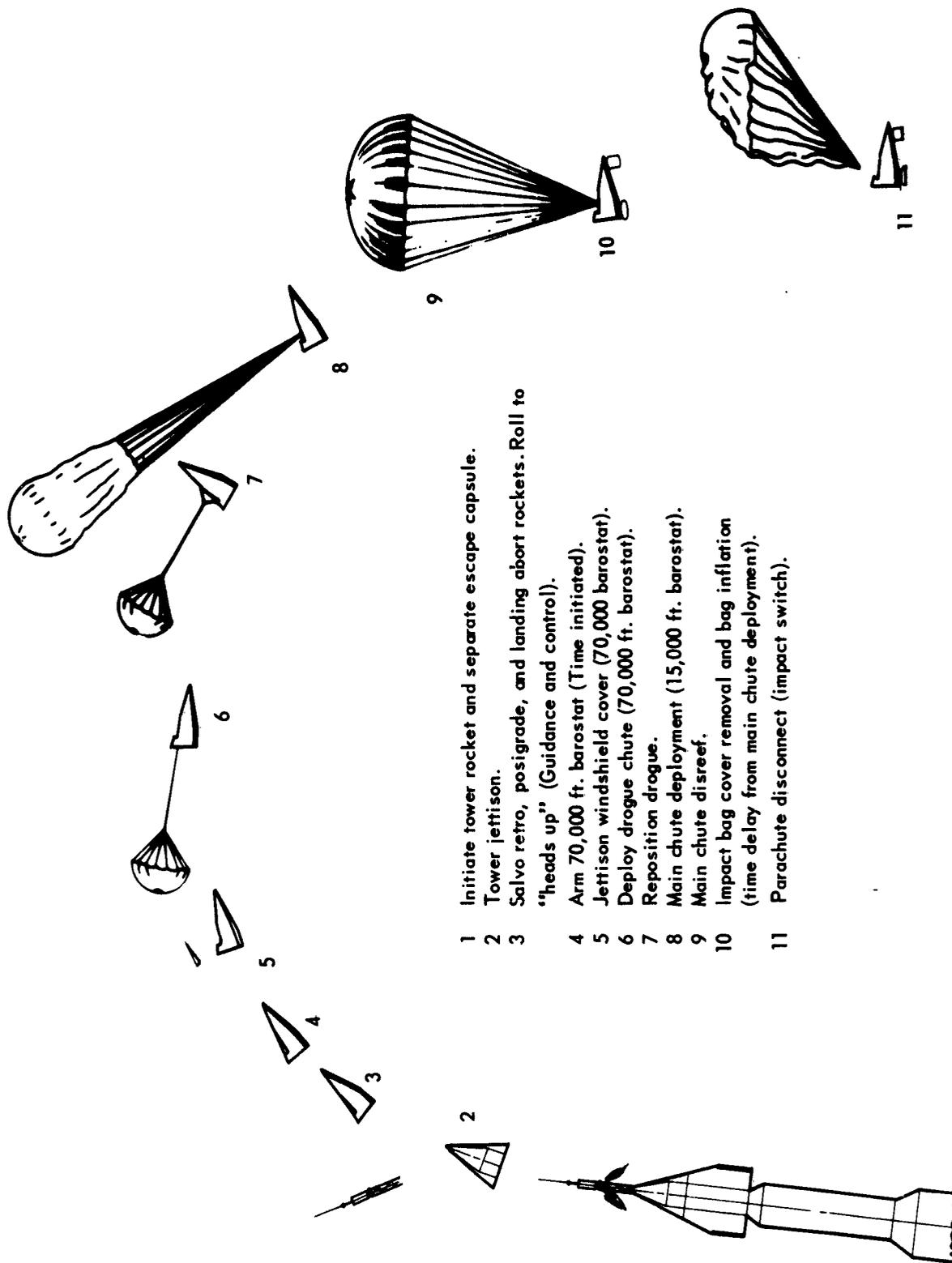
1. Initiate tower rocket and separate escape capsule.
2. Tower jettison.
3. Salvo retro, posigrade, and landing abort rockets. Roll to "heads up" (Guidance and control).
4. Arm 70,000 ft. barostat (Time initiated).
5. Jettison windshield cover (70,000 barostat).
6. Deploy drogue chute (70,000 ft. barostat).
7. Reposition drogue.
8. Main chute deployment (15,000 ft. barostat).
9. Main chute disreef.
10. Impact bag cover removal and bag inflation (time delay from main chute deployment).
11. Parachute disconnect (impact switch).

FIGURE 6   MODE B ABORT
ESCAPE DURING BOOST WHEN H > 50,000 FT.

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1 Fire escape rockets and separate capsule
2 Jettison tower
3 Salvo fire retrograde, posigrade and landing abort rockets
4 Roll to "heads up" attitude
5 Release and jettison windshield cover
6 Mortar drogue
7 Reposition drogue
8 Drogue release (allowing main chute deployment)
9 Main chute disreef
10 Jettison impact bag covers and inflate bags
11 Impact — main chute disconnect and recovery operations
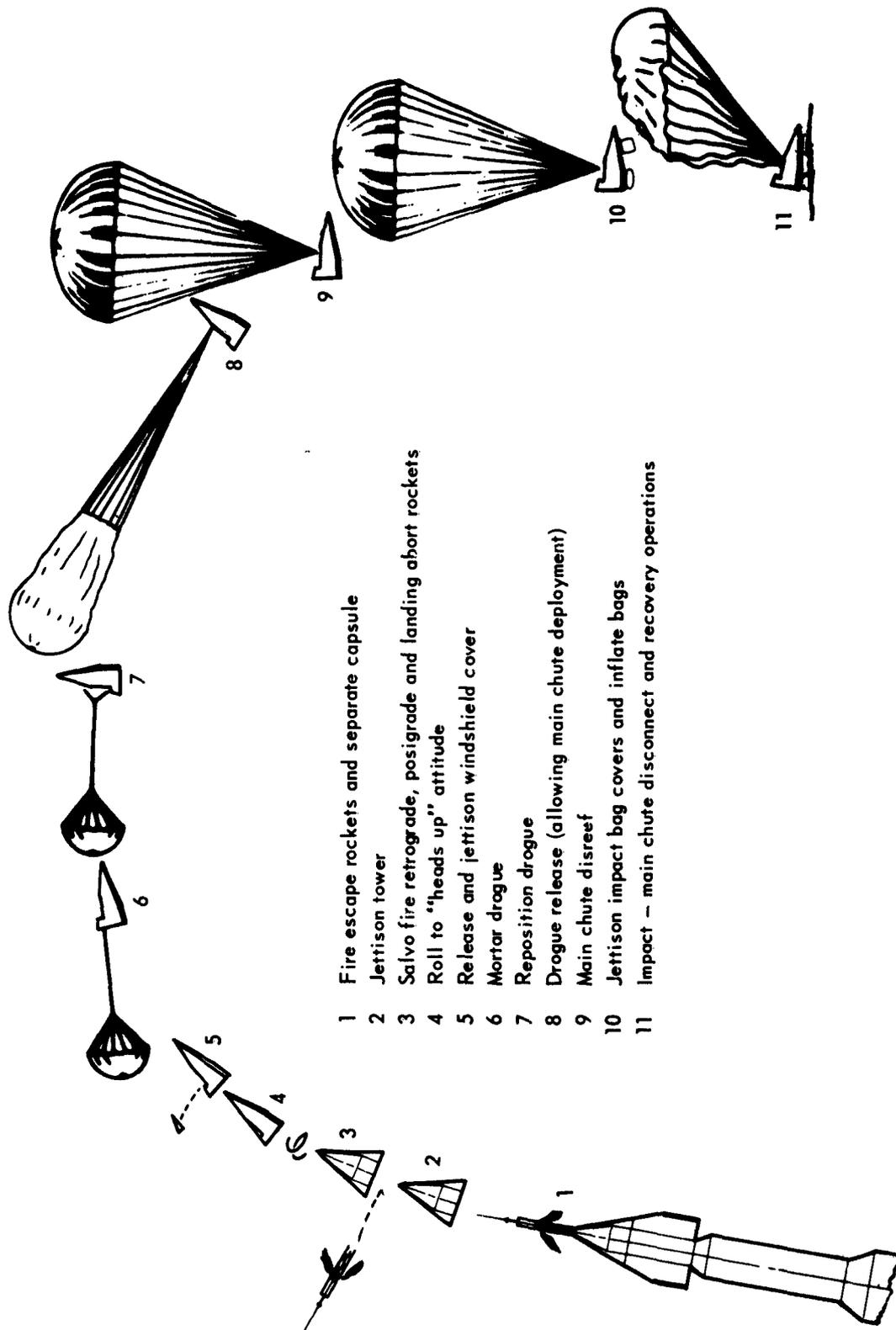
FIGURE 5   MODE A ABORT
ESCAPE OFF-THE-PAD OR DURING EARLY BOOST (H < 50,000 FT.)
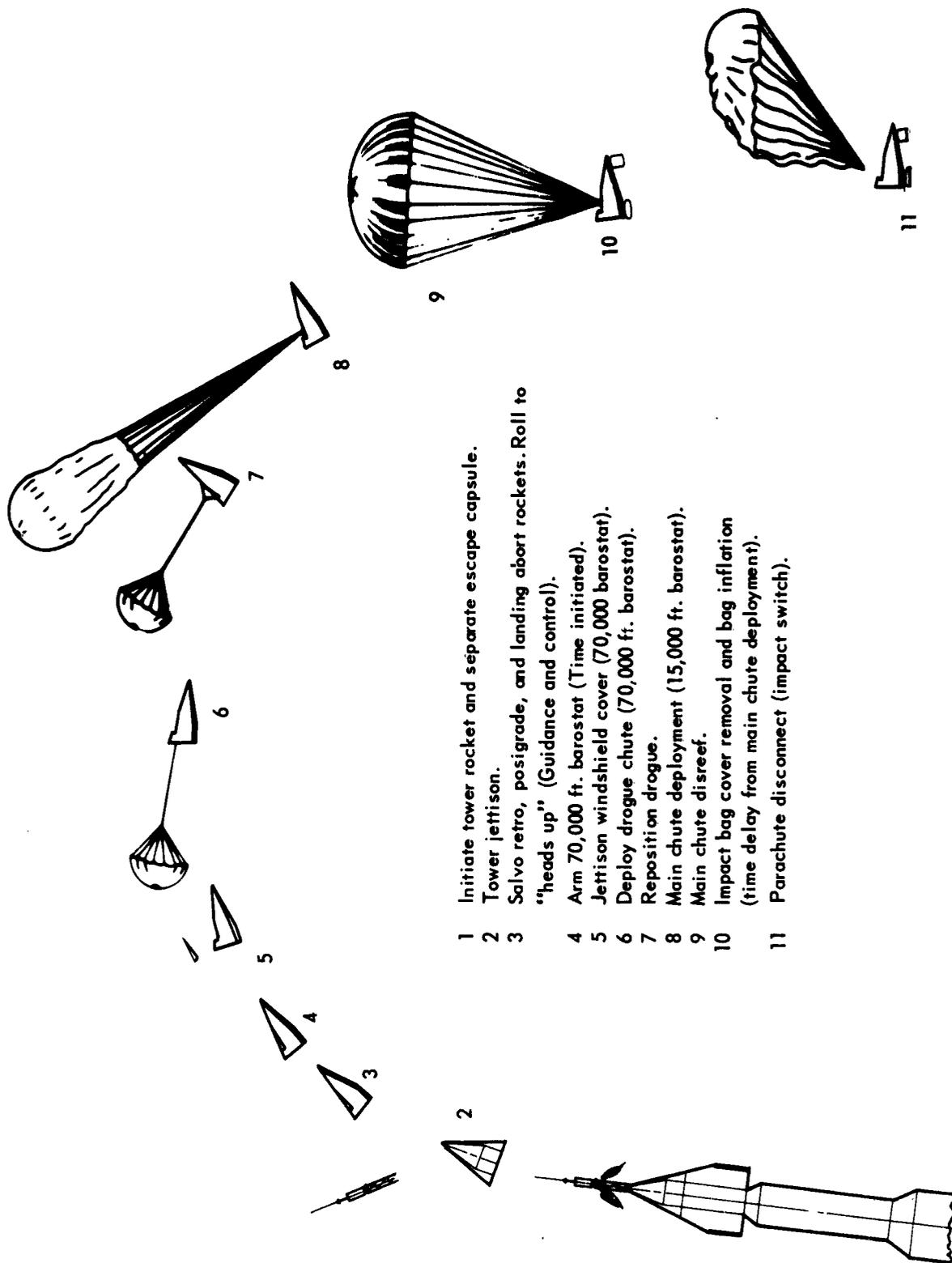
1 Initiate tower rocket and separate escape capsule.
2 Tower jettison.
3 Salvo retro, posigrade, and landing abort rockets. Roll to "heads up" (Guidance and control).
4 Arm 70,000 ft. barostat (Time initiated).
5 Jettison windshield cover (70,000 barostat).
6 Deploy drogue chute (70,000 ft. barostat).
7 Reposition drogue.
8 Main chute deployment (15,000 ft. barostat).
9 Main chute disreef.
10 Impact bag cover removal and bag inflation (time delay from main chute deployment).
11 Parachute disconnect (impact switch).

FIGURE 6   MODE B ABORT
ESCAPE DURING BOOST WHEN H > 50,000 FT.
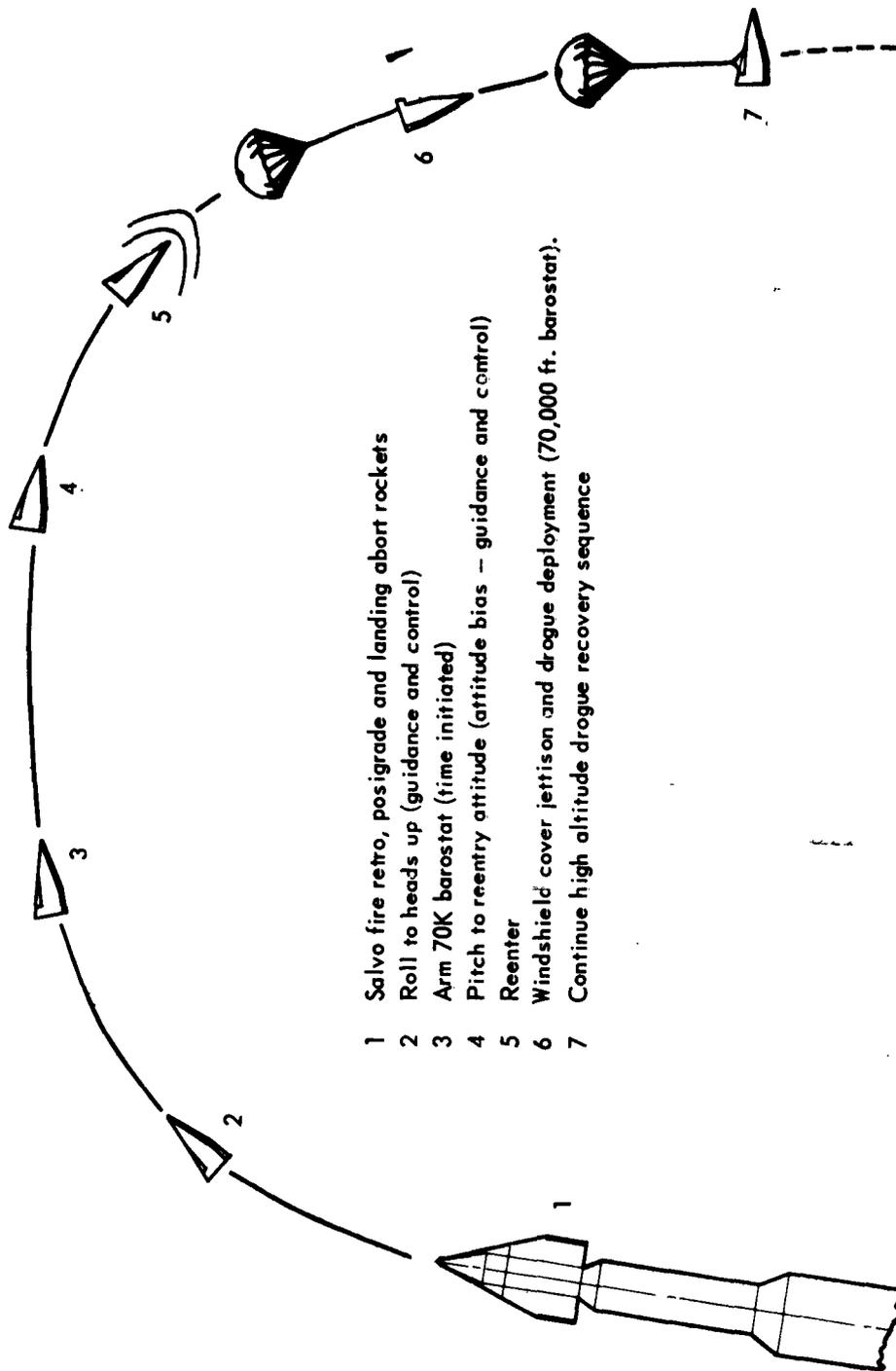
1 Salvo fire retro, posigrade and landing abort rockets
2 Roll to heads up (guidance and control)
3 Arm 70K barostat (time initiated)
4 Pitch to reentry attitude (attitude bias – guidance and control)
5 Reenter
6 Windshield cover jettison and drogue deployment (70,000 ft. barostat).
7 Continue high altitude drogue recovery sequence

FIGURE 7   MODE C ABORT
ESCAPE DURING LATTER LAUNCH PHASE (PRE-ORBITAL)
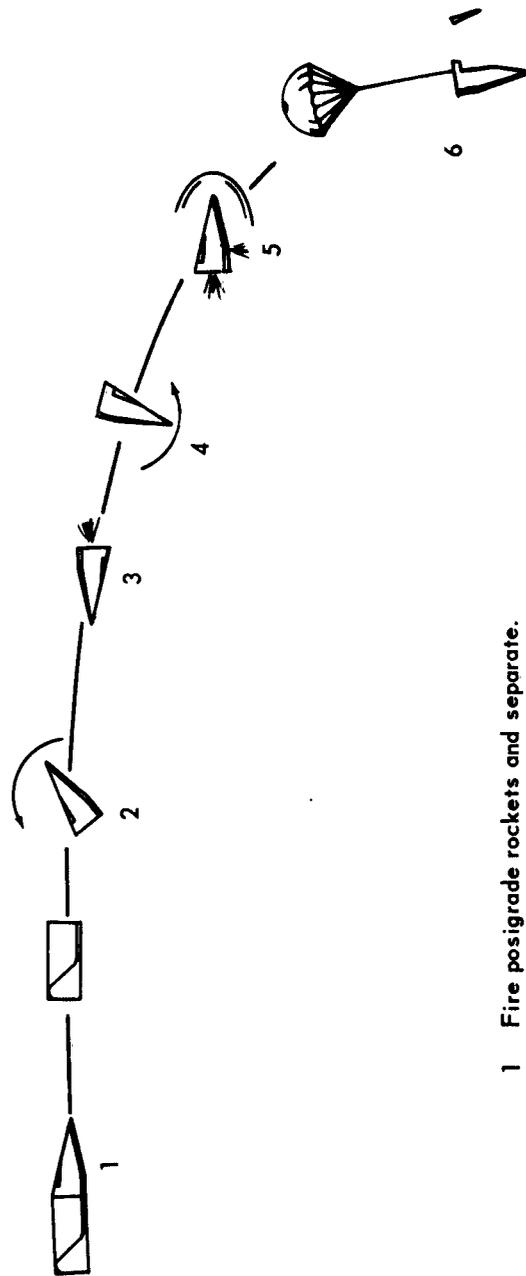
1 Fire posigrade rockets and separate.
2 Pitch to retro attitude (attitude bias — Guidance and control).
3 Ripple fire retrograde rockets.
4 Pitch to re-entry attitude (attitude bias — Guidance and control).
5 Re-entry (fire landing rockets and unused retro rockets).
6 Initiate recovery system (70,000 ft. barostat).

FIGURE 8   MODE D ABORT
ESCAPE FROM ORBIT
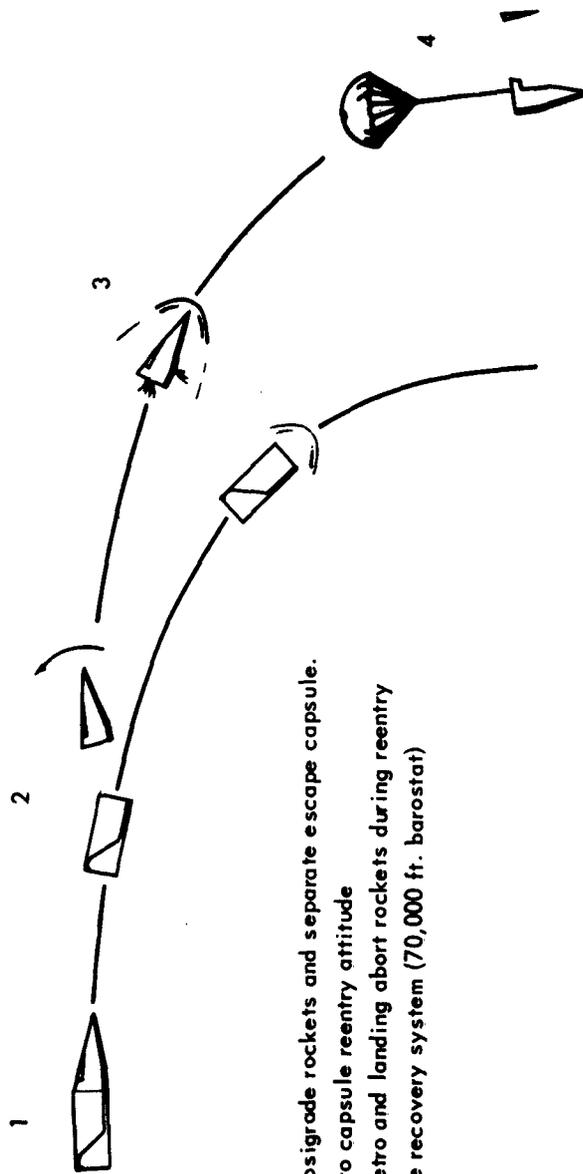
1 Fire posigrade rockets and separate escape capsule.
2 Pitch to capsule reentry attitude
3 Burn retro and landing abort rockets during reentry
4 Initiate recovery system (70,000 ft. barostat)

FIGURE 9 MODE E ABORT
ESCAPE AFTER VEHICLE RETROGRADE, PRIOR TO RE-ENTRY

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1 Salvo fire 1, 2, or 3 retrograde rockets.

2 Arm 70,000 ft. barostat (time delay) . Burn unused rockets during re-entry.

3 Initiate recovery system (70,000 ft.)

FIGURE 10   MODE F ABORT
ESCAPE DURING RE-ENTRY

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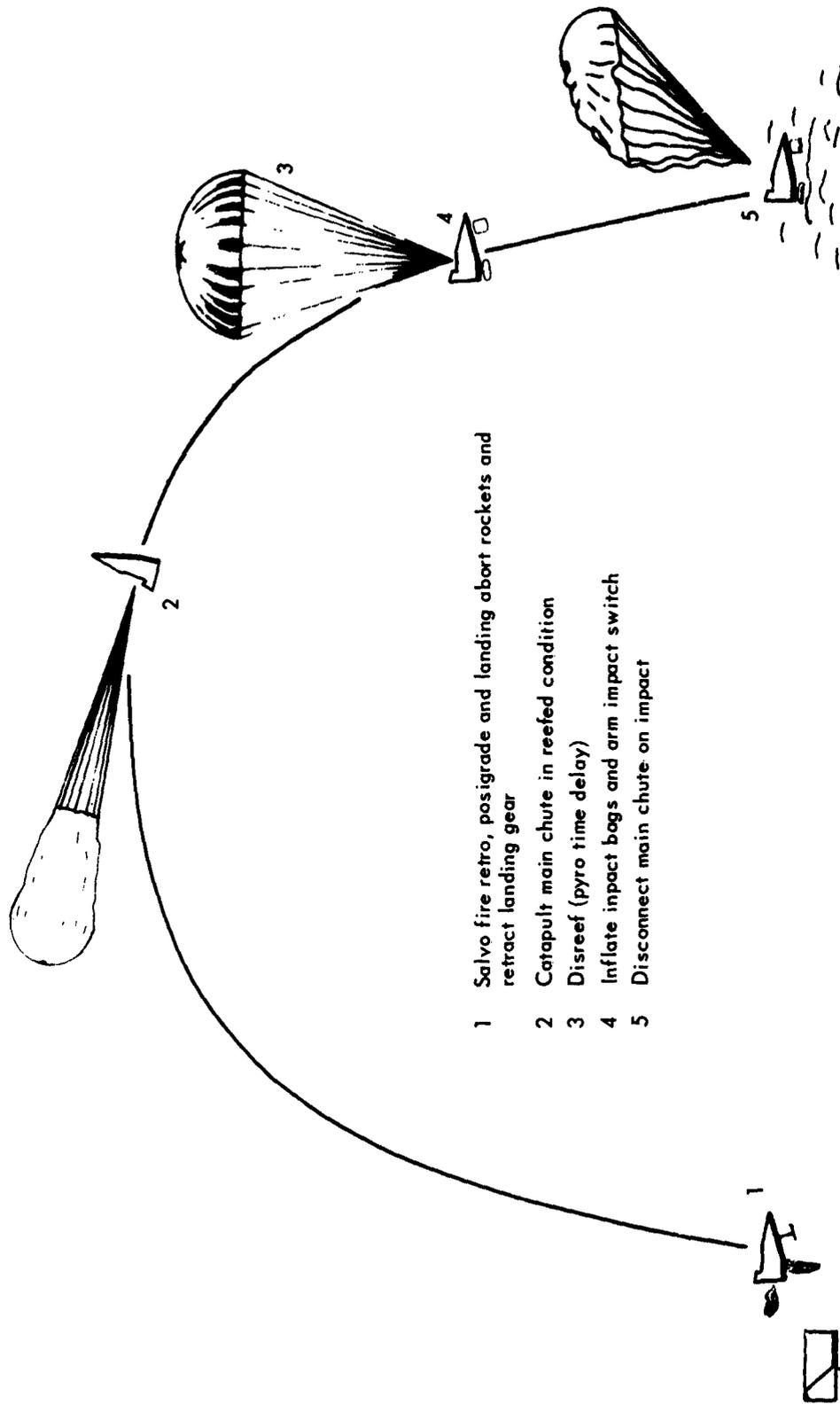
1. Salvo fire retro, posigrade and landing abort rockets and retract landing gear
2. Catapult main chute in reefed condition
3. Disreef (pyro time delay)
4. Inflate inpact bags and arm impact switch
5. Disconnect main chute on impact

**FIGURE 11 MODES G/H ABORT
ESCAPE DURING LOW ALTITUDE GLIDE AND LANDING**

flight path, and altitude limits from which the escape capsule can be recovered safely. The approach to a boundary beyond which a safe recovery can no longer be accomplished is sufficient cause for abort.

The limits for specific abort modes, establishing the points in the flight path at which a change is made from one abort mode to the next, are based primarily on the known characteristics of the escape and recovery system.

If an abort mode limit is approached or crossed, a new abort mode is selected. If the boundary of all modes (the envelope of flight paths from which safe abort can be accomplished) is approached, an abort in the preselected mode is indicated.

The paragraphs to follow will present the advantages of the selected abort system. Two-degree-of-freedom point-mass analyses were used on the launch trajectories where the dynamic characteristics were felt to be less critical. Because of the sudden change in angle of attack which occurs during a landing abort, the pitch characteristics of the escape capsule were considered in a three-degree-of-freedom longitudinal analysis. Three-degree-of-freedom point-mass analysis was used for reentry trajectories.

2.1.3.1 Modes A and B

Launch aborts within the atmosphere require the use of high acceleration rockets to avoid the dangers associated with a booster malfunction environment. The rockets are mounted on an escape tower which is jettisoned after the rockets are fired, or as a normal mission function at the end of the Mode B abort region. The tower concept was selected because of the low payload penalty and proven performance reliability as discussed in Part I of this report.

All retrograde and landing abort rockets are initiated simultaneously after the escape-rocket burnout and tower jettison. The separation produced by the retrograde rockets supplements the action of the escape rockets and allows the use of the full drogue recovery sequence. Although redundant to the escape tower system because of the similar impulse and thrust direction, the retrograde rockets do not provide sufficient thrust to expeditiously separate the escape capsule from the malfunction environment. Neither do they provide adequate separation thrust for the maximum dynamic-pressure condition during launch. A throttlable nozzle would be required if a single-rocket system were to be used for both the escape tower and retrograde functions. Although marginal to the current state of the art, some discussion of dual-nozzle hardware is presented in another section. Some modification of the recovery-system sequencing would be required to incorporate such a system.

The landing-abort rockets provide lateral-separation capability in the escape capsule. The lifting characteristics of the capsule also provide

lateral-separation capability but an analysis is not presented because no problems basic to the abort-system definition were anticipated.

Modes A and B are identical in the escape system sequencing as described in the preceding paragraphs. Once the drogue chute is deployed, the recovery sequence is also the same. The conditions of deployment of the recovery system constitute the only difference in the two modes of abort. In Mode A the drogue parachute is mortared on the ascending side of the abort trajectory, while in Mode B it is mortared on the descending side. This is accomplished without a mode-selector change by use of a 10-second time delay and a 70,000-foot barostat. The recovery system is initiated after the delay unless the altitude is greater than the barostat setting. The barostat acts as a lockout until the escape capsule again returns to 70,000 feet. Examples of these trajectories at the Mode A/B crossover are shown in Figures 12 and 13.

The 10-second time delay is based on the recovery criteria shown in Figure 14. The ordinate represents the recovery-system initiation-time delay. It is bounded by drogue-parachute design limits of dynamic pressure and Mach number on the lower side and inflation characteristics on the upper side. The criterion for good inflation characteristics was arbitrarily established at a dynamic pressure of 50 psf, the average terminal dynamic pressure for the capsule on the drogue. The selected time delay of 10 seconds is shown to be within the established boundaries. Figure 15 shows the most critical dynamic-pressure trajectory.

The 70,000-foot barostat was selected on the basis of recovery conditions following orbital and near-orbital aborts. It represents the lowest altitude commensurate with drogue-parachute design-Mach-number limitations. However, this barostat setting also avoids problems associated with Mach number in the Mode B region, as can be seen by the Mach boundary in Figure 14.

Because of the redundancy in longitudinal thrust capability, off-pad abort presents no serious problems. Figure 16 is an abort and recovery trajectory showing the recovery altitude to be 2100 feet, using the full drogue recovery sequence.

2.1.3.2 Modes C through F - Preorbital, Orbital, Post-Retrograde, and Re-entry

These modes are designed for abort during the latter-launch phase, orbital abort, post-retrograde abort, and abort during re-entry. The recovery technique for each employs the high-altitude drogue for stabilization and deployment of the landing parachute for control of impact velocity. Figure 17 shows the histories of performance parameters such as velocity and dynamic pressure while Figure 18 shows angular excursion during a typical recovery following an orbital abort. The justification for the system has been well documented in Part I of this report, so a redundant analysis will not be undertaken in this report. The bulk of the discussion will
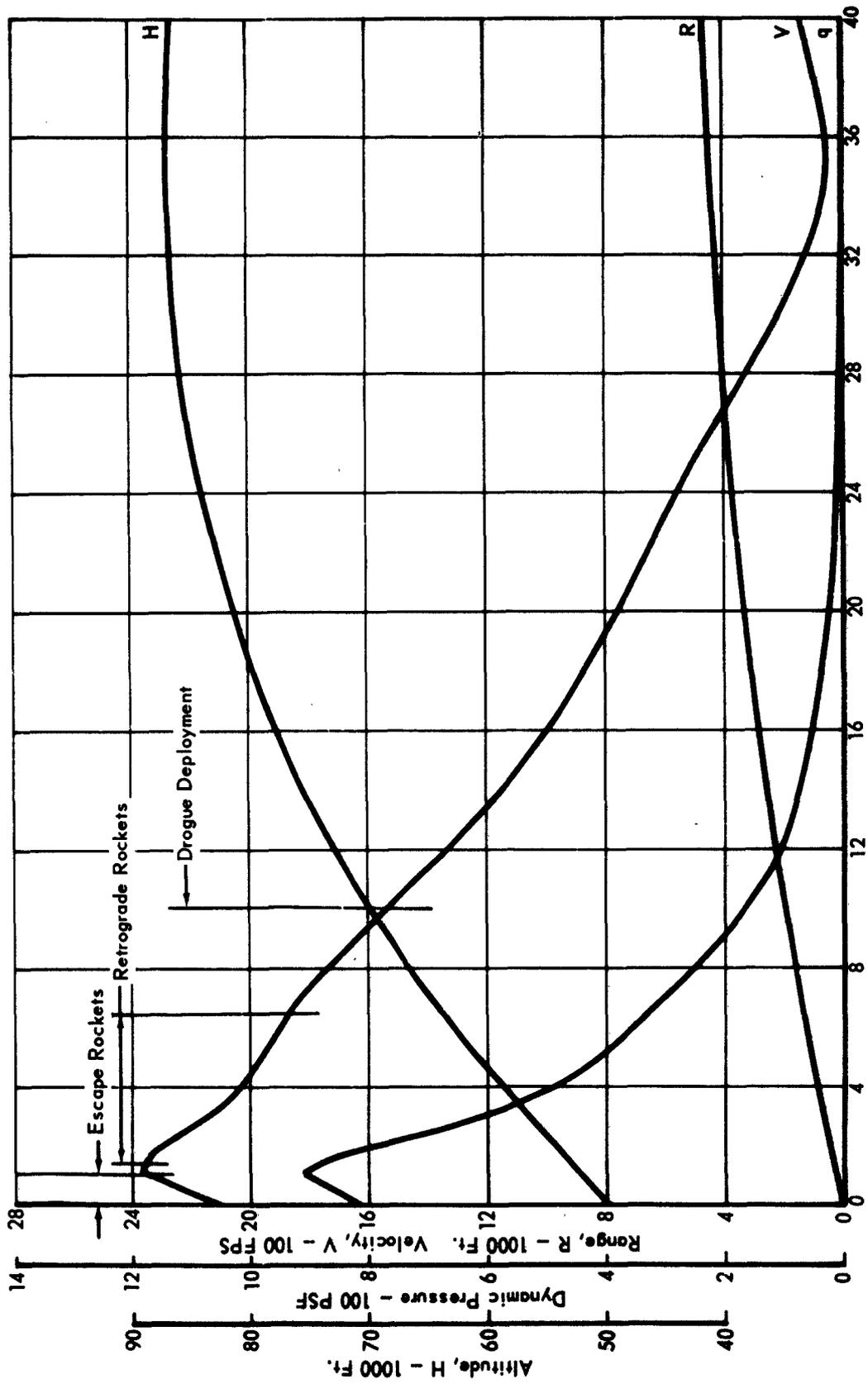
FIGURE 12 – MODE A ABORT, UPPER ALTITUDE BOUNDARY
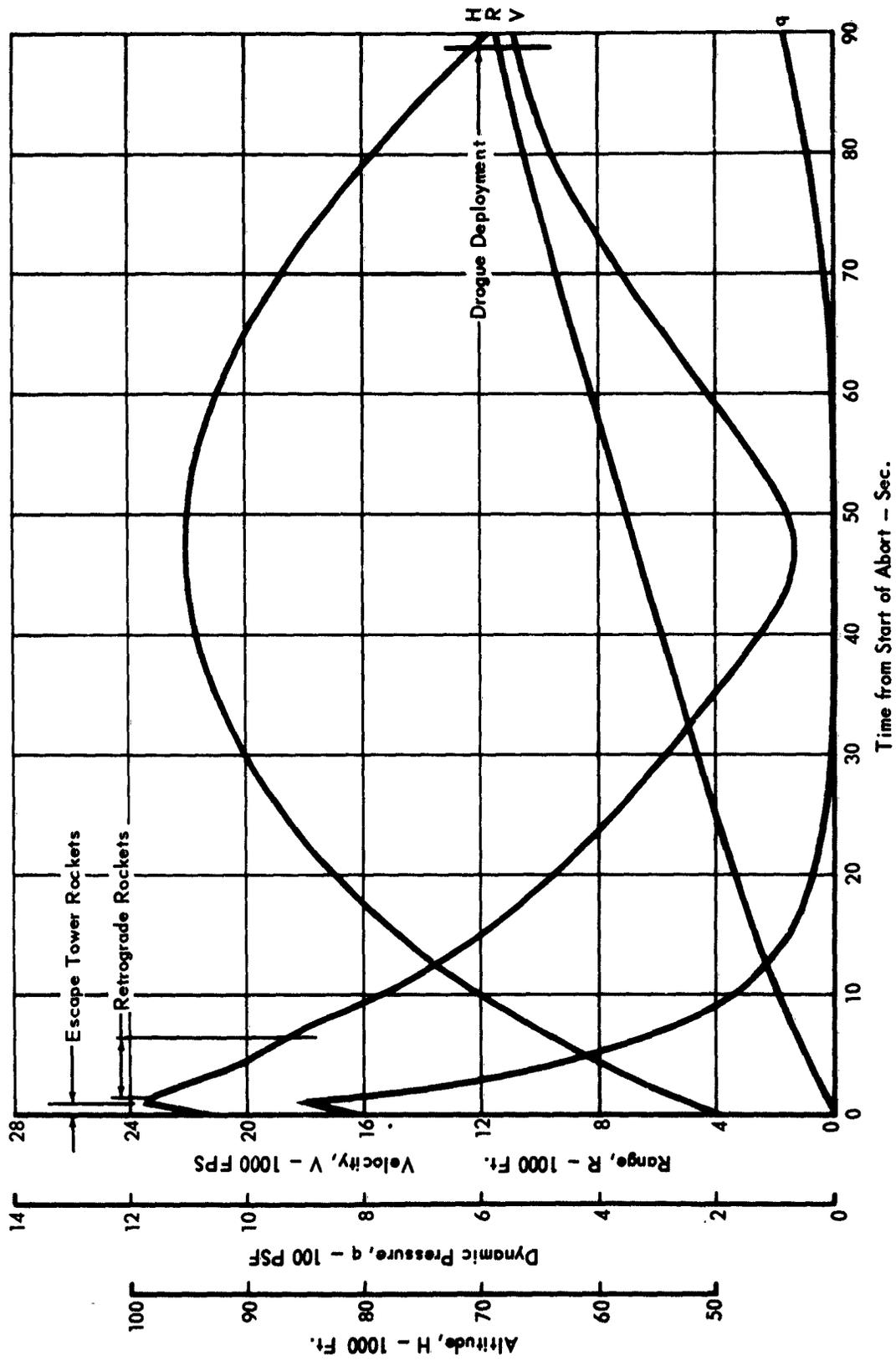
FIGURE 13 — MODE B ABORT, LOWER ALTITUDE BOUNDARY
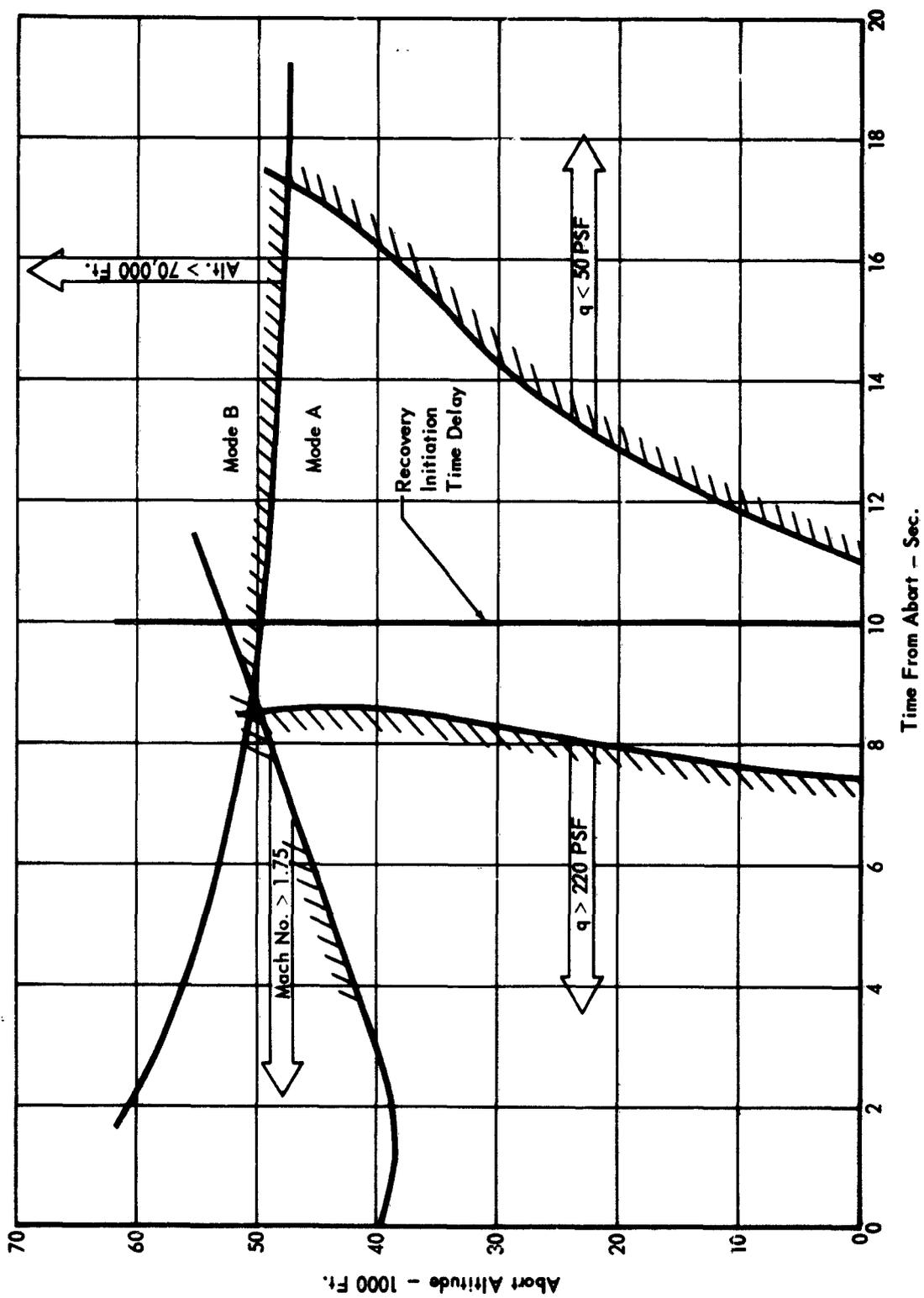
FIGURE 14 – RECOVERY CRITERIA, MODE A ABORT

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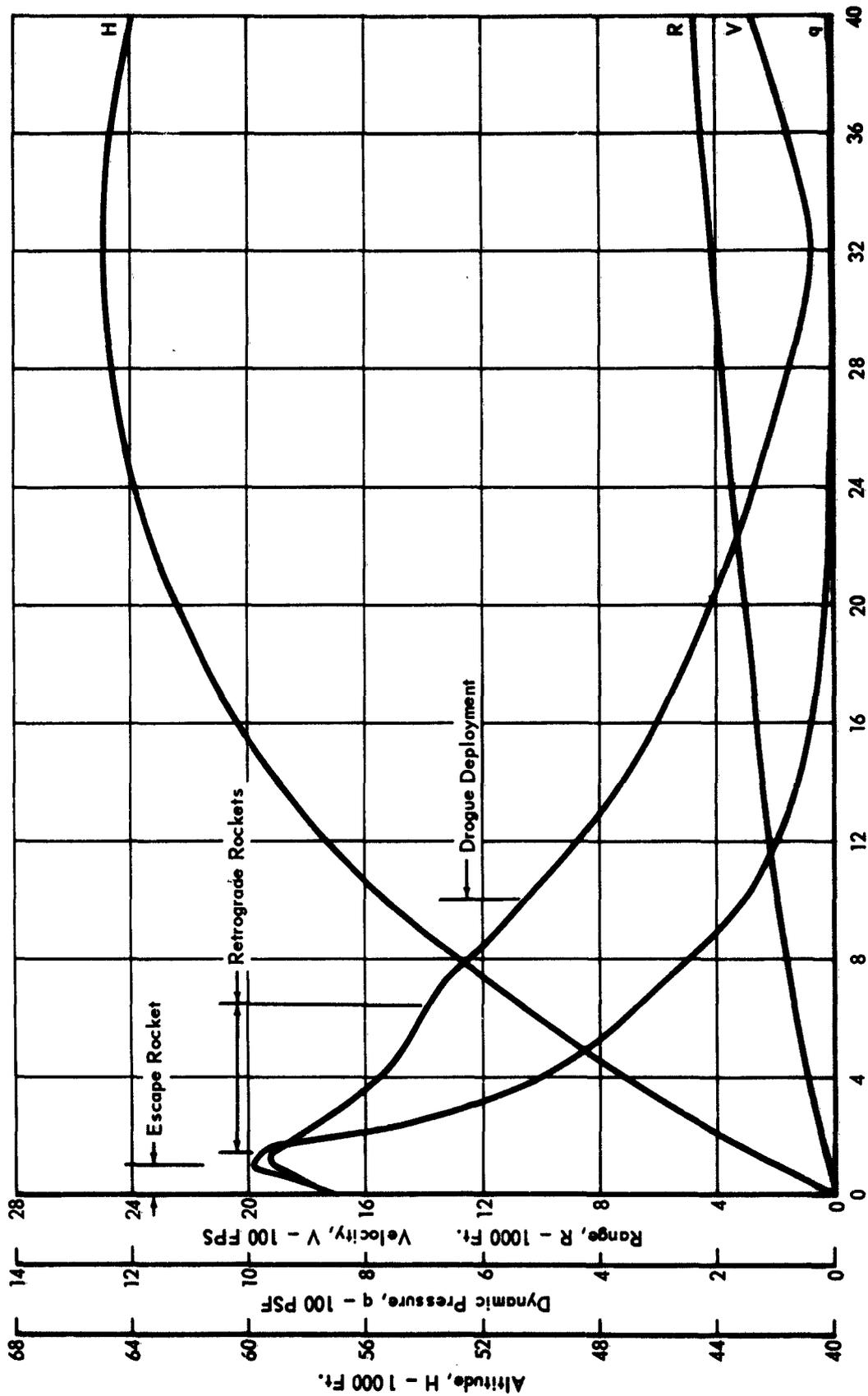
FIGURE 15 – MODE A ABORT, MAXIMUM DYNAMIC PRESSURE
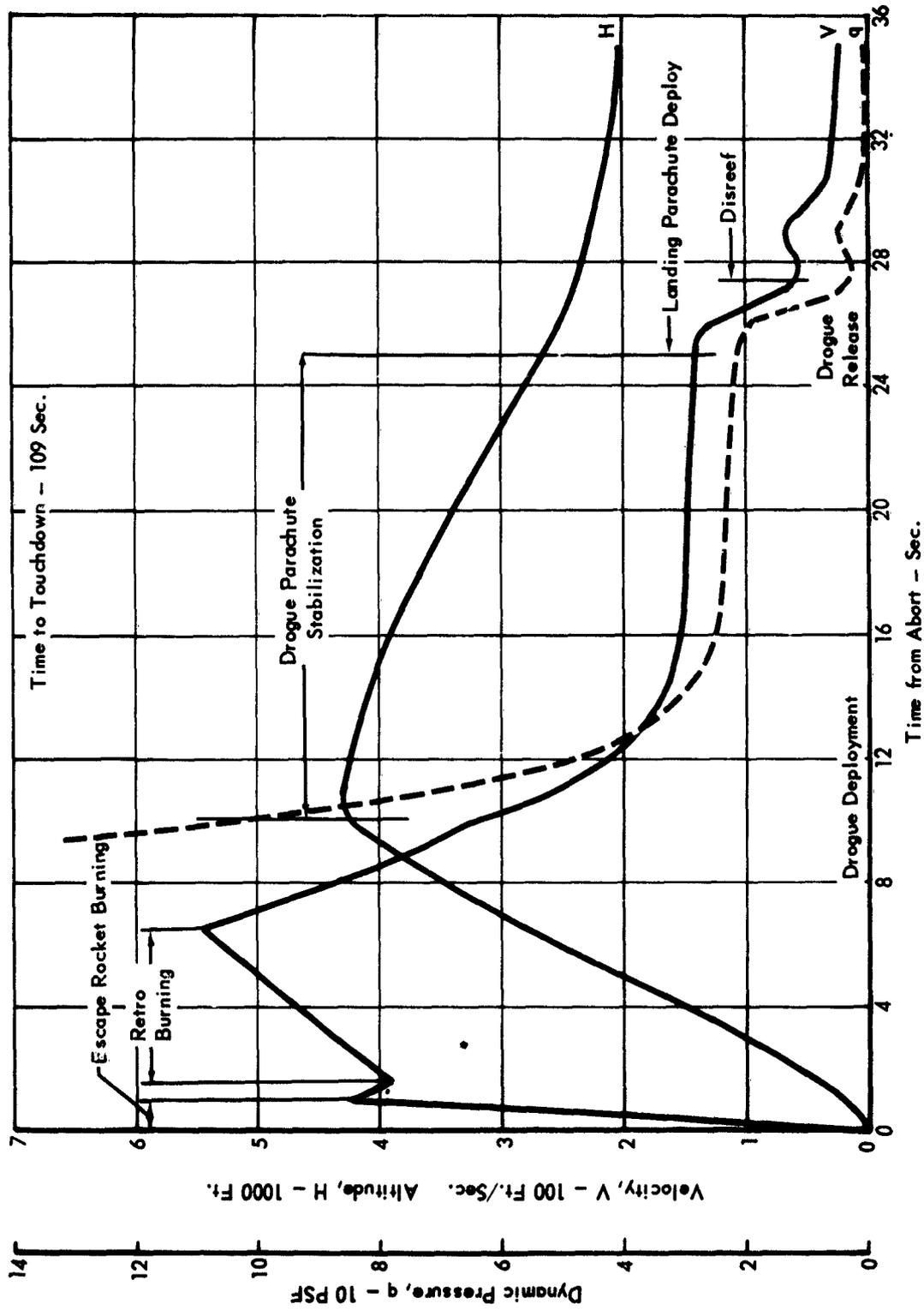
FIGURE 16 – MODE A ABORT OFF THE PAD
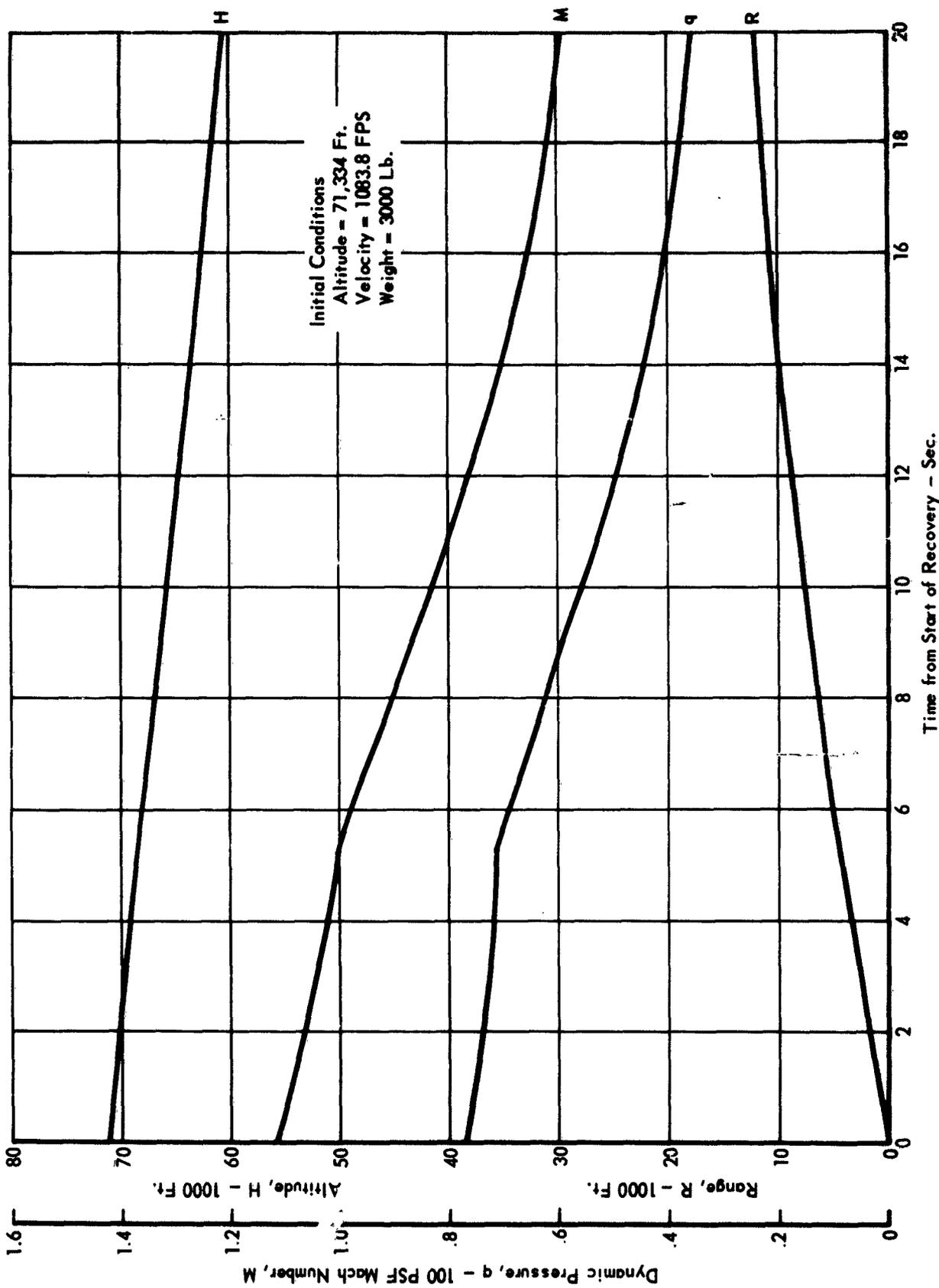
FIGURE 17 – HIGH ALTITUDE RECOVERY, MODE D
ABORT PERFORMANCE HISTORY

Initial Conditions
Altitude = 71,334 Ft.
Velocity = 1083.8 FPS
Weight = 3000 Lb.

26
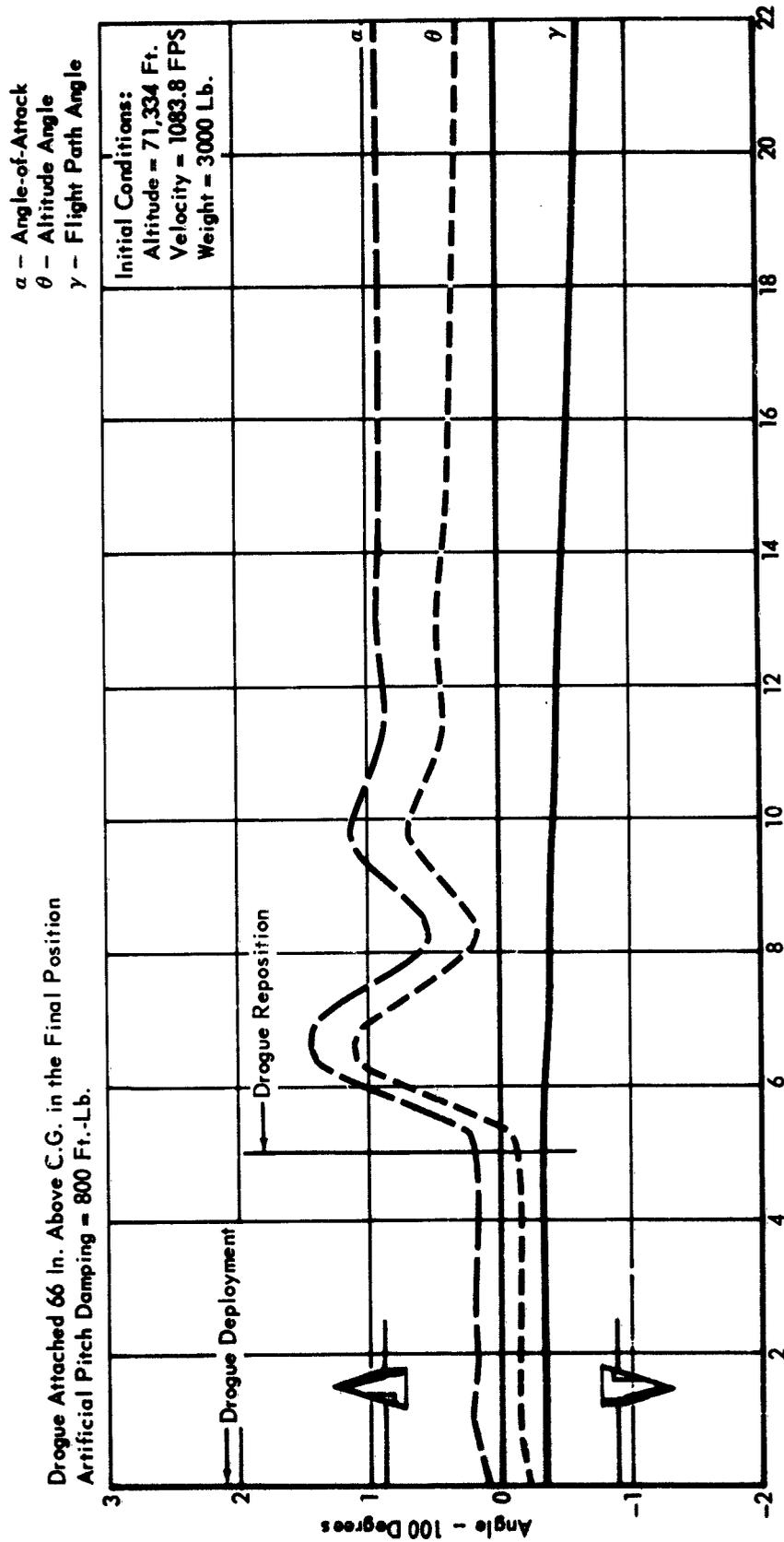
FIGURE 18 – HIGH ALTITUDE RECOVERY, MODE D ABORT ANGULAR EXCURSIONS

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center around the guidance and control system. This system is indicated by the dotted outline in Figure 4.

The success of the orbital and near-orbital abort modes depends on the proper operation of the guidance and control system. The heart of the abort guidance is the computer. It provides the real-time histories of the flight parameters based on input from an inertial measuring unit, a system of accelerometers, whose signals are integrated and converted to useful information displayed for the pilot. The resulting velocity, flight-path angle, and altitude discretes are compared with preselected abort values in the abort guidance subprogram for determination of the abort type that will be initiated, for activation or deactivation of the rockets necessary to accomplish the abort successfully, and for initiation of the unused rockets before the start of recovery. In addition to the computer functions during orbital and near-orbital aborts, angular bias for re-entry attitude and, in the case of an orbital abort, retrograde attitude is summed with the gyroscope output to provide proper attitude control during specific phases of the aborts. When bias is not added, only roll and yaw control is maintained by action of the reaction-control system.

Since the abort system must be automatic, that is, it must be usable even though the pilot is incapacitated, heavy reliance is placed on the capsule gyroscope, reaction control system, and computer. Therefore, the use of the computer for control of the orbital and near-orbital aborts appears not to be an undue complication of the system. As a by-product of this design philosophy, all modes in this group can be initiated by actuation of the abort handle after a single selection on the instrument panel. This transfers the function of mode selection from the pilot to the computer during this region and reduces the total number of manual mode selections to three.

Abort boundaries represent the span of flight parameters within which the spacecraft must be maintained through the mission. They are based on re-entry criteria such as heating and load factor. In other words, the spacecraft must always fly within the velocity, flight-path angle, and altitude limits from which the escape capsule can safely be recovered should an abort become necessary. The approach to a boundary beyond which a safe recovery can no longer be accomplished is sufficient cause for abort.

These boundaries are based on the particular mission parameters such as launch heading, launch-trajectory profile, insertion altitude, etc. They are computed for the specific combinations of rockets before the mission and the information is stored in the computer accessible to the abort-guidance subprogram. The actual flight parameters are compared with the boundary values and the abort mode limits throughout the flight. If an abort-mode limit is approached or crossed, a new mode or rocket combination is selected. If the boundary of all modes and preselected rocket combinations (envelope of boundaries) is approached, an abort is indicated

in the mode currently selected. The selection criteria are stored in the computer and the pyrotechnic switches controlling the abort are not actually ignited until the abort is initiated.

The normal progression of retrograde rocket selection is as follows:

During most of Mode C, all rockets are selected. As the orbital conditions are approached and the possibility of accelerating the vehicle to orbit with the retrograde rockets is evident, one retrograde rocket is deactivated at a time. Mode D, from which all retrograde rockets are fired for deceleration, is activated as orbital conditions are reached. Mode E is selected at the initiation of normal retrograde, and all retrograde rockets on the escape capsule are deactivated. Mode F is initiated at the start of re-entry, but with a single retrograde rocket armed. As re-entry progresses and the possibility of skip-out at abort diminishes, the second and then the third rocket are armed. All rockets remain activated throughout the remainder of the mission.

After an abort and the start of re-entry, the unused retrograde rockets are ignited automatically as the velocity, flight-path angle, and altitude conditions which supply the signal to arm them are reached. The provisions for expending the unused rockets are necessary for controlling the c.g. location during re-entry, and are desirable for safety at impact.

The landing-abort rockets are never fired if re-entry is to follow because capsule heat protection afforded by the heat shield (compartment covers) would be removed when the rockets are fired. The criterion for initiating the landing-abort rockets is velocity, which must be less than 5000 fps. This velocity is well below critical re-entry heating velocity, and more importantly, corresponds to an altitude during launch, below which the landing abort rockets are needed for ejection out of the plane of the launch-vehicle trajectory. The rocket usage extends beyond the Mode B abort region, where the escape-tower impulse is not available but where diminishing dynamic pressure reduces the requirement for lateral separation.

The attitude bias also is an important part of the abort guidance. In modes C, D, and E, re-entry pitch attitude bias is summed with the gyroscope output after the selected rockets have fired. In Mode C, the time delay is six seconds to allow time for salvo-firing the retrograde rockets. But in Mode E, the time delay is one second, allowing only time for the posigrade rockets to fire. In Mode D, the signal for re-entry bias emanates from the retrograde rocket intervalometer. Retrograde-attitude bias is applied one second after abort initiation. The retrograde rockets are not fired until the flight director needles (outputs) are nulled and then only if the interrupt option has not been exercised.

2.1.3.3 Mode G/H - Low-Altitude Glide and Landing

Preliminary investigation of system requirements indicated that two

separate abort modes would be required in the flare-out and landing regions. It was believed that the modes would be similar because close ground proximity in both cases would not only deem inadvisable the use of the full drogue sequence, but also suggest another deployment technique suitable for both. Therefore, provisions for a landing parachute catapult were integrated into the recovery system. However, different recovery system initiation-time delays were anticipated, due to the abort time available after a post-landing abort on the one hand and the anticipated longer delay required for dynamic pressure bleed-off after an abort from a steady-state glide on the other. Detailed investigation disclosed the latter problem to be insignificant in the light of the stringent design requirements of the landing parachute, so the modes have been combined into a single abort mode having a recovery system initiation-time delay of 10 seconds. The sequence is shown in Figure 19.

The abort from the parent glider at dead stop after a normal landing dictated the time delay for recovery initiation. The range-altitude trajectory for this abort is shown in Figure 20. The dynamic pressure at deployment is 28 psf. A time delay longer than 10 seconds would allow further dynamic pressure bleed which would jeopardize the good inflation characteristics and thus actually reduce the recovery altitude. The recovery altitude, based on a rate of descent less than 30 fps, is about 2250 feet.

Abort during a steady-state glide results in the highest dynamic pressure following abort, but Figure 21 shows that a 10-second time delay will allow the dynamic pressure to bleed off to within safe limits before the landing parachute is deployed. The recovery altitude for this case is shown to be 1400 feet above the abort location in Figure 19.

The excursions in angle of attack, flight-path angle, and attitude are shown for the post-landing abort in Figure 22. To fully utilize the capsule lift and achieve the good recovery characteristics shown, requirements for stabilizing flaps and a parachute bridle have been incorporated. The flaps provide a trim point at 10-degree angle of attack, thus eliminating the violent pitch-up of an unflapped capsule which would result in a loop and possible crash in the vicinity of the abort scene. The bridle arrangement moves the effective parachute attack point 66 inches above the c.g. This eliminates the tendency for the capsule to oscillate under the parachute canopy, and improves the landing characteristics.

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Aero Center Shifted 6 Inches Aft at Abort Initiation

Landing Parachute Confluence Point is 66 In. Above C. G.

Pitch Damping – 800 Ft.-Lb.

Alt. = 2000 Ft.
Vel. = 283 FPS
X_{DC} = 110 In.
X_{CG} = 116 In.

Ref. Area = 88 Ft.^{2}
Para. Dia. = 69 Ft.

12.9 Sec. – Disreef

10 Sec. – Landing Parachute Deployment
q = 90.8 PSF

20 Sec.

5 Sec. – Retrarocket Burnout

.67 Sec. – Landing Abort Rocket Burnout

Altitude, H – 100 Ft.

Range, R – 100 Ft.
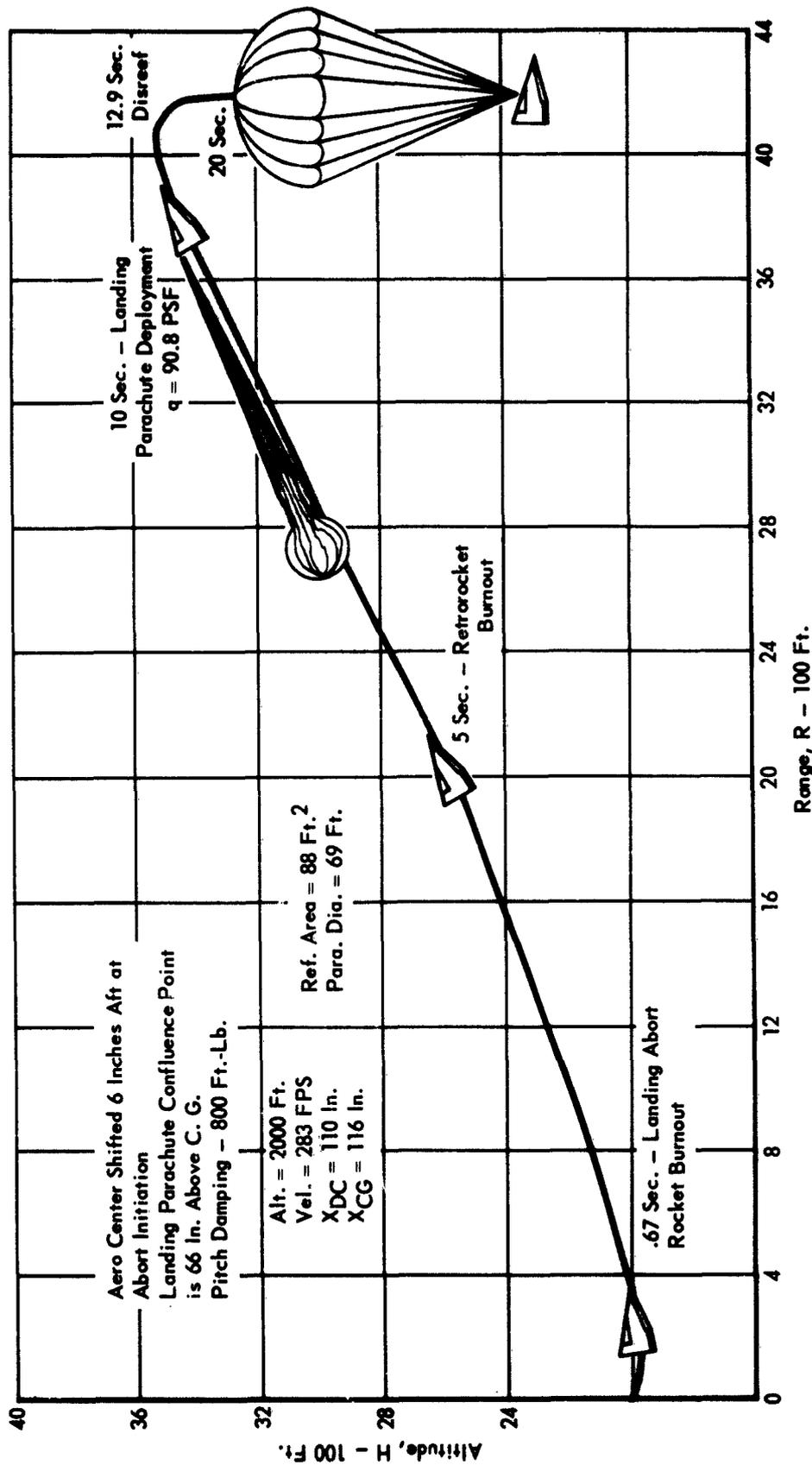
FIGURE 19 – MODE G/H ABORT FROM STEADY STATE GLIDE

Range – Altitude Trajectory

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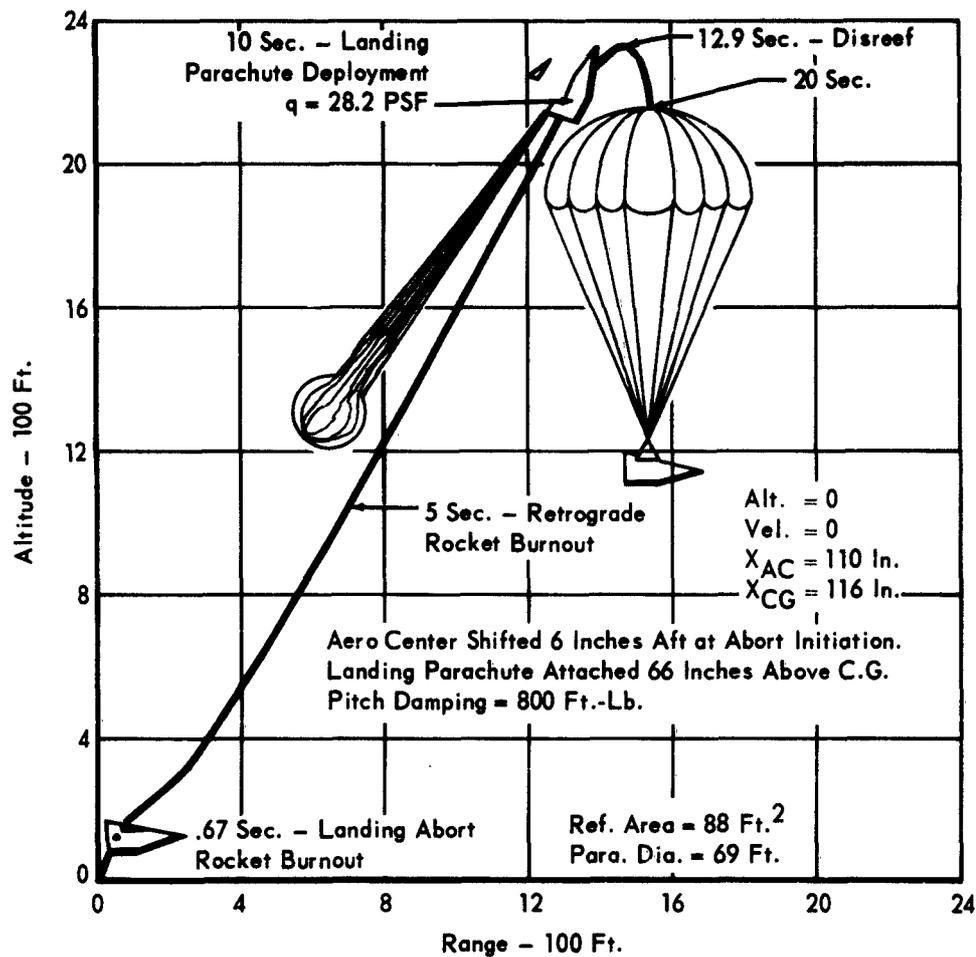
FIGURE 20 – MODE H ABORT, POST LANDING

Range-Altitude Trajectory
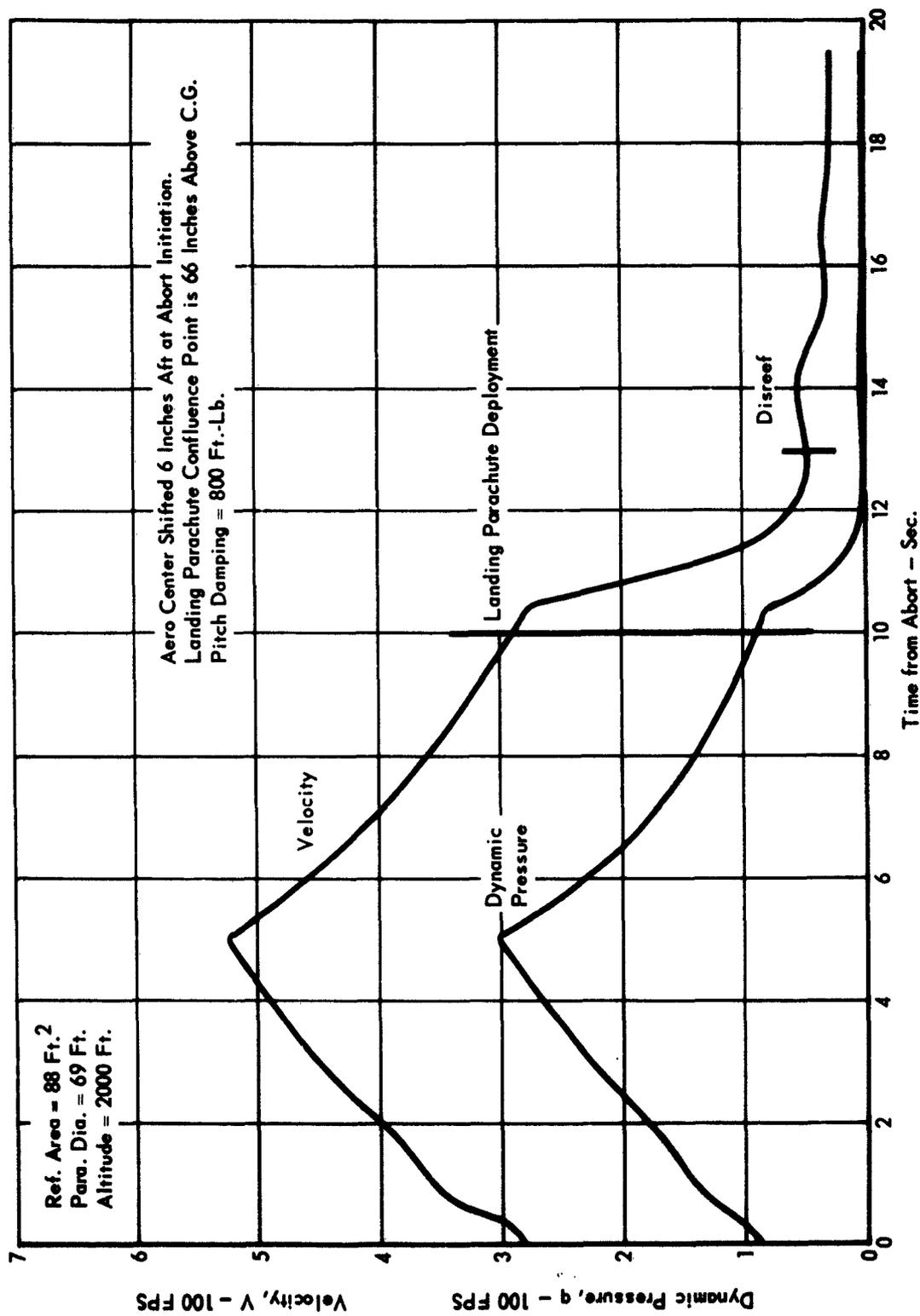
FIGURE 21 – MODE G/H ABORT FROM STEADY STATE GLIDE
TIME HISTORY OF VELOCITY AND DYNAMIC PRESSURE
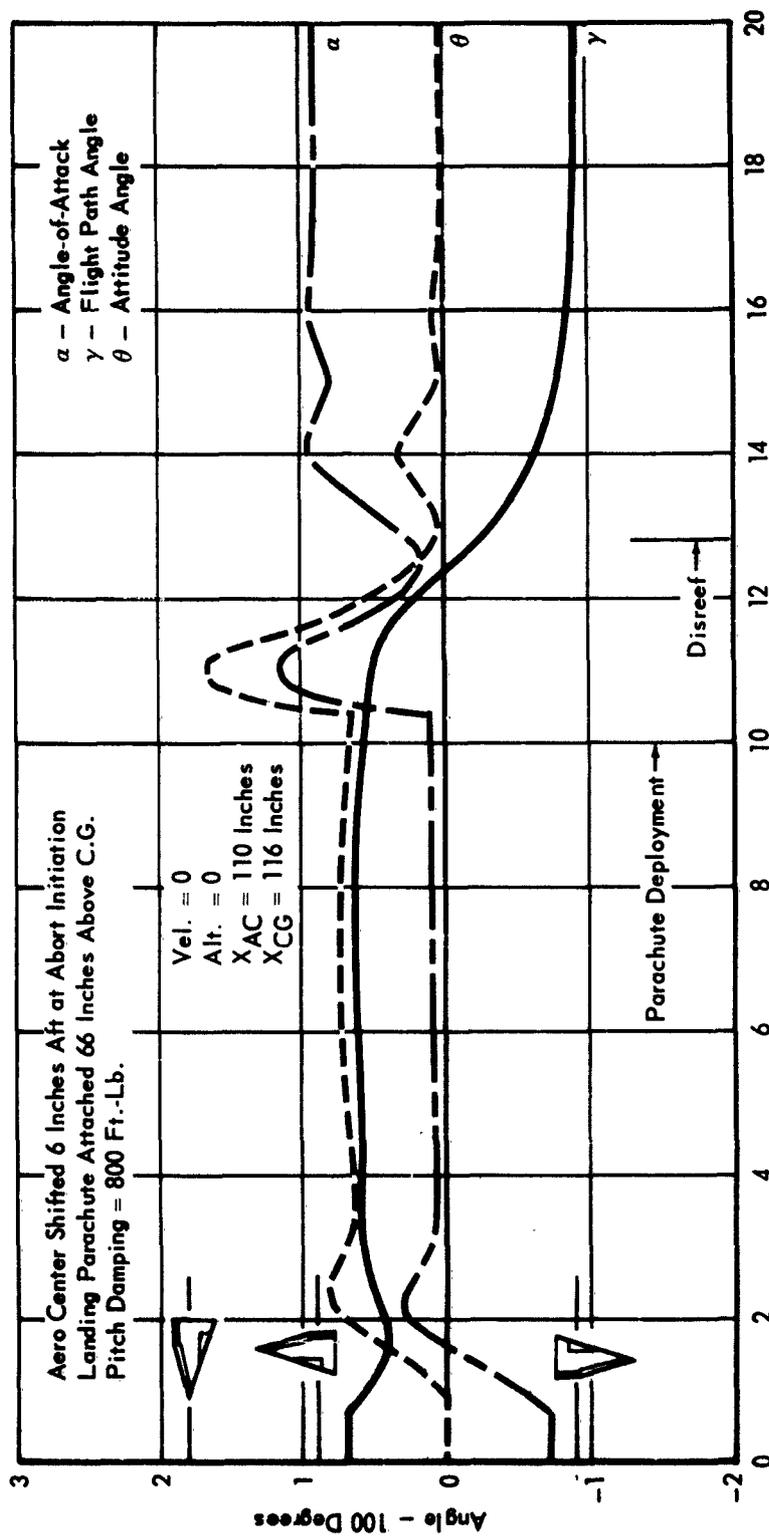
FIGURE 22 – MODE H ABORT, POST LANDING
TIME HISTORY OF ANGULAR EXCURSIONS

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2.2 Subsystem Design

2.2.1 General

In order to facilitate the discussion and presentation of the designs associated with each PAD function, the overall escape system, which was shown schematically in Figure 4, has been separated into seven distinct subsystems. These may be designated as follows:

>   Separation and Severance
>   Tower Release and Jettison
>   Landing Abort Rocket Subsystem
>   Windshield Cover Release and Removal
>   Recovery
>   Impact Attenuation and Flotation
>   Landing Gear Subsystem

In the design of each subsystem, prime consideration was given to such factors as the necessity of simultaneity of operation, reliability, and commonality or multiple use of standardized components. In particular, attention was concentrated on the use of standard initiation and stimulus transfer components. In view of the lack of specific details on structures and heat paths, the environmental design criteria for subsystem and component design were considered to be essentially the same as those discussed in Part I of this report. These are shown in the Appendix. The operational design criteria for each subsystem hinged around the selection of an optimum initiation technique offering the maximum degree of reliability, and the use of design concepts which, by past history, have been proved capable of accomplishing the desired function with the optimum combination of weight, space, and reliability considerations.

Because of the large number of initiation points involved, and the comparatively large spatial dispersion of components to be initiated from a given impulse, it was deemed essential that the initiation and stimulus transfer system be low in weight, small in size, function almost instantaneously, and be capable of transferring a firing signal over long lengths without the use of intermediate boosters.

2.2.2 Reliability

In the design of aerospace vehicles, reliability has become, and shall continue to be, one of the most important design considerations. The point in time when when a system, subsystem, or individual component is most vulnerable to becoming a low-reliability item is when the item is in the initial design stage. Therefore, it is necessary that each design engineer maintain a responsible and ever-alert attitude toward reliability. If a designer ever abdicates his own personal responsibility for product reliability, the results can be catastrophic.

Although reliability can be enhanced by proper design, often it becomes necessary to incorporate certain redundancies within a given system to achieve a required reliability. The concept of redundancy as applied to most systems has generally been concerned with time-dependent components with specific failure rates. As such, the system unreliability is distributed among the system components and generally is not concerned with interconnects or junctions. The

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realibility of such a system, as depicted below, can be defined by the following:
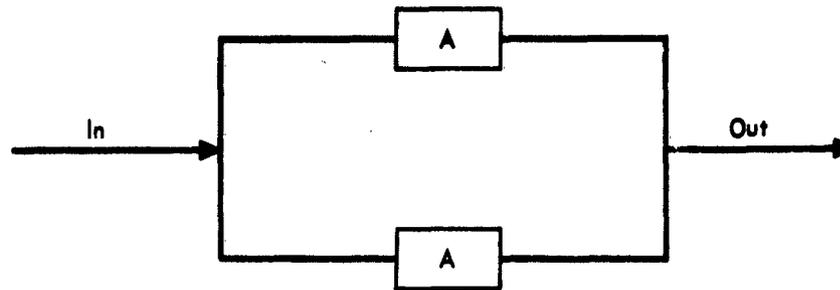
$$R_s = \left[1 - (1 - R_A)(1 - R_A) \right]$$

where R_s represents system reliability and R_A, component reliability.

Pyrotechnic systems, however, consist of discrete functions or success-failure trails. The reliability or the probability of success, therefore, is defined by:

$$R = P_s = S/N$$

where S represents the number of successes and N the number of trials.

For pyrotechnic systems the prime mode of failure is the failure to initiate a component. Once initiation is achieved, pyrotechnic components exhibit a high probability of success. The chief method of improving reliability is to provide redundancy of the complete units, or nearly as good, to provide a plurality of means of initiating each unit. Because initiation represents the prime mode of failure, and each junction of an MDC stimulus transmission system involves cross-initiation, reliability calculations must consider each of these junctions between components, as well as the components themselves. Redundancy within pyrotechnic circuits should then be determined in accordance with this concept.

To illustrate the concept of redundancy in a subsystem utilizing SMDC for stimulus transfer, consider a hypothetical "pyrotechnic circuit" involving the following components:

o   A three-tip junction block, as shown in Figure 31, Page 54. This device resembles, in function, a "tee" fitting in a hot-gas initiation system; i.e., one input is converted into two outputs or either of two inputs will activate one output.

o   Any type of PAD having dual SMDC initiation. Either SMDC tip actuates or causes the PAD to perform its function, and will also cross-initiate to the other SMDC tip. The tubing cutter and sealer shown in Figure 38, Page 71, is such a device.

Assume the PAD to have reliability R_A of operating if stimulus reaches it, regardless of whether cross-initiation occurs, and reliability R_T to cross-initiate SMDC whether or not the PAD functions.

Also, assume that any junction block has the reliability R_T to cross-initiate to any other SMDC tip.

First, consider a portion of a subsystem in which one PAD function, F, must occur and an output stimulus must reach point O. Also, assume that if more than one identical PAD are used, only one need function to meet the operational requirements.

Consider first a redundant, dual-initiation system, in which two identical PAD (designated A and B for convenience) are used.
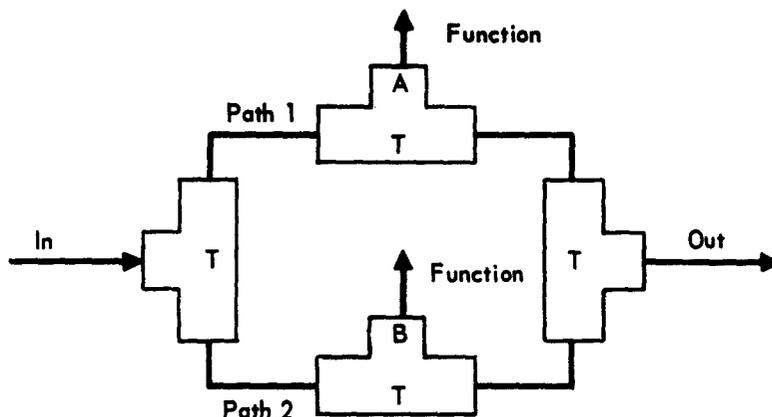
Either A or B must work <u>and</u> stimulus must transfer out.

Reliability of A working by Path 1

$R_{A_1} = (R_T)(R_A)$, where R_A considers all requirements of functioning if stimulus is received.

Reliability of A working by Path 2

$R_{A_2} = (R_T)(R_T)(R_T)(R_A)$

Overall reliability of A working is:

$$R_{F_A} = \left\{ 1 - \left[1 - (R_T)(R_A) \right] \left[1 - (R_T)(R_T)(R_T)(R_A) \right] \right\}$$

Also, reliability of B working is equal to that of A; i.e., $R_{F_B} = R_{F_A}$

Thus, reliability of either one or the other working, and thus functional requirements being met is:

$$R_F = 1 - (1-R_{F_A})(R_{F_B}) = 1 - (1-R_{F_A})^2$$

Reliability of output occurring by transfer through Path 1 is:

$$R_{O_1} = (R_T)(R_T)(R_T)$$

Reliability of output occurring through Path 2 is same.

Thus overall reliability of getting output stimulus is:

$$R_O = 1 - (1-R_{O_1})(1-R_{O_2})$$

$$= 1 - (1-R_T^3)(1-R_T^3)$$

Reliability of either A or B working **and** getting output stimulus is:

$$R_{sys} = (R_F)(F_O)$$

Conversely, the reliability of accomplishing function A **and** getting a signal output in a nonredundant system which does not include dual paths is based on the following:
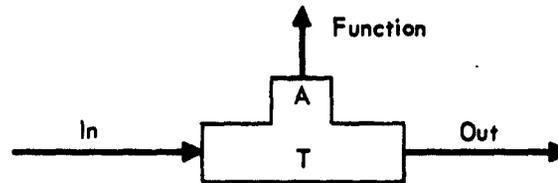
$$R_F = R_A$$

$$R_O = R_T$$

$$R_{sys} = (R_F)(R_O) = (R_A)(R_T)$$

To compare reliabilities in vivid and convenient (but unrealistic) numbers, let

$$R_A = .8 \text{ and } R_T = .9$$

Then for first system (redundant, etc.)

$$R_{F_A} = \left\{ 1 - (1-.72)(1-.526) \right\}$$

$$= 1 - (.28)(.474)$$

$$= 1 - .133$$

$$= .867$$

$$R_F = 1 - (.133)^2 = 1 - .0176$$

$$= .9824$$

$$R_O = \left\{ 1 - (1-.9^3)(1-.9^3) \right\} = 1 - (1-.73)^2 = 1 - .27^2$$

$$= 1 - .073$$

$$= .927$$

$$R_{sys} = R_F \cdot R_O = (.9824)(.927) = .91$$

Whereas, in the straight-through system,

$$R_{sys} = .9 \times .8 = .72$$

From the preceding illustration, the advantage of using a system which provides a dual path to, and dual initiation of, each PAD is obvious. The pyrotechnic subsystems developed and described throughout this report were designed in accordance with the concepts presented above.

Studies have shown that when explosives are manufactured under rigid quality controls, the occurrence of failure due to exposure to storage environments is virtually nonexistent. However, aging of these materials can be a factor in reliability, and, if extreme, can contribute to an unacceptable reduction in the number of discrete success trials.

"Service" environmental conditions, which are usually far more severe than storage environments, can be a significant factor in the reliability of pyrotechnics or explosives. This is particularly true in the case of temperature and temperature cycling. Therefore, a comparison of the material's characteristics with the service environmental envelope, and the determination of a safe service life, are essential to the attainment and retention of high system reliability.

2.2.3 Elements Common to Most Subsystems

A number of elements are common to all or most of the subsystems involved in the escape and recovery system for the study vehicle. These include the ignition elements, the various stimulus transfer components, and various delay elements and pyrotechnic switches. For optimum clarity and to avoid the redundancies of discussion which would otherwise occur, these groups of components will be discussed in the following paragraphs, and henceforth only briefly called out in the ensuing sections covering specific subsystems.

2.2.3.1 Initiation

Two basic modes of initiation are used in the escape and recovery system. These are electrical and explosive; that is, the use of an electrical impulse to ignite the first element of a pyrotechnic train (be it an igniter or a detonator), or the initiation of a primer or an explosive charge from the output of another explosive charge, such as the output from shielded mild detonating cord (SMDC).

Since the utilization of the output from SMDC for initiation is, in essence, merely a stimulus transfer technique, and will be thoroughly covered in Section 2.4.1.2, the discussion of "initiation" under this section will be limited to electric initiators.

The term electric initiator covers a very broad range of electrically initiated ordnance devices, and includes such items as electric matches, primers, detonators (including blasting caps, glow plugs, and squibs). Basically they are explosive or pyrotechnic in nature, and are used to start an "explosive train" or ignite a propellant charge. Generically they can be divided into two classes; squibs, which produce hot gases, incandescent particles (often at high speed), and radiant energy; or detonators, which produce a shockwave necessary in the initiation of explosives.

The electric initiator, therefore, may be described as an electro-chemical transducer which converts electrical energy from a suitable power supply into chemical energy in the form of detonations or pyrotechnic reactions. Since the electro-explosive device (EED) is the bridge between the electrical system and the ordnance system, it becomes a key to many critical functions in ordnance and missile systems.

(a) Design Considerations

In order for an initiator to meet its key role, the following design points should be considered:

o   Functional capability - it must be able to produce the desired effect upon initiation within a specified time.

o   Reliability - it must function with a high degree of probability at a high confidence level.

o   Safety - it must be designed to resist shock, vibration, thermal environments, and electrical inputs from direct or inductively coupled sources.

o   Producibility - it must be capable of being manufactured in an industrial system geared to the production of many identical units in a continuous process, where critical in-line function parameters can be carefully inspected. This permits statistical analysis and evaluation.

o   Versatility - it should be capable of performing a variety of functions or it should be capable of being designed for specific input and output requirements.

Ideally, it is desirable to design the unit with an ability to have a signature-type input which can be modified to fit a specific electrical system, and an output which can be tailored to a given function.

(b) Basic Initiator Designs

Electric initiators may be constructed in either of two basic forms - the "plug and shell" type and the "header" type. Both contain the same basic components, but are quite distinct in their design and application. The first type has been widely used because of its simplicity of manufacture and, therefore, its low cost. Present designs consist of a rubber or plastic plug injection molded around the lead wires. Earlier styles potted the lead wires in place. In either case these plugs were crimped or sealed into a thin plastic or metal shell containing the explosive or pyrotechnic composition (Figure 23a). The "header" type on the other hand provides a direct pressure sealed barrier into the case. This is achieved by molding the lead wires (in this type of design they actually are pins) into a machined metal body using ceramic, glass or other dielectric materials to provide both a pressure seal and insulation for the conductive pin or pins (Figure 23b). The machined body can be quite complex in design, depending upon the application in which it is to be used.

(c) Design of Ignition Element

There are several different designs for converting an electric stimulus into thermal or kinetic energy in order to start the self-sustaining exothermic reaction in the explosive train. These are wire bridges, carbon bridges, conductive mixes, spark gaps, and exploding bridge wires (EBW). The choice of which ignition system should be used is dependent upon a number of factors such as:

o   Safety - is a safe-arm device involved?

o   Environment - including temperature, RF and static susceptibility

o   Power available

o   Volume available

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(a) Plug & Shell Type

*Note: Dimensions for diameter and length are open.

Main charge (optional)
Spacer
Booster charge
Shunt
Lead wires
Molded plug
Gilding metal or aluminum case

(b) Header Type

Compression glass header
Potting compound
Sleeve
Insulating disc.
Closure disc.
Solder
Main charge
Ignition mix
Machined metal body
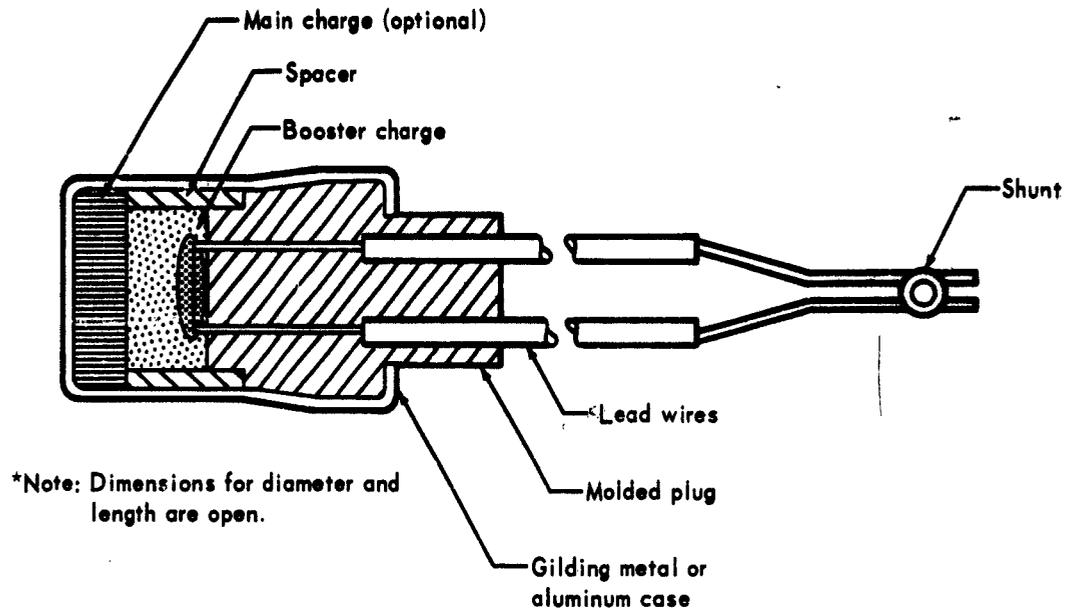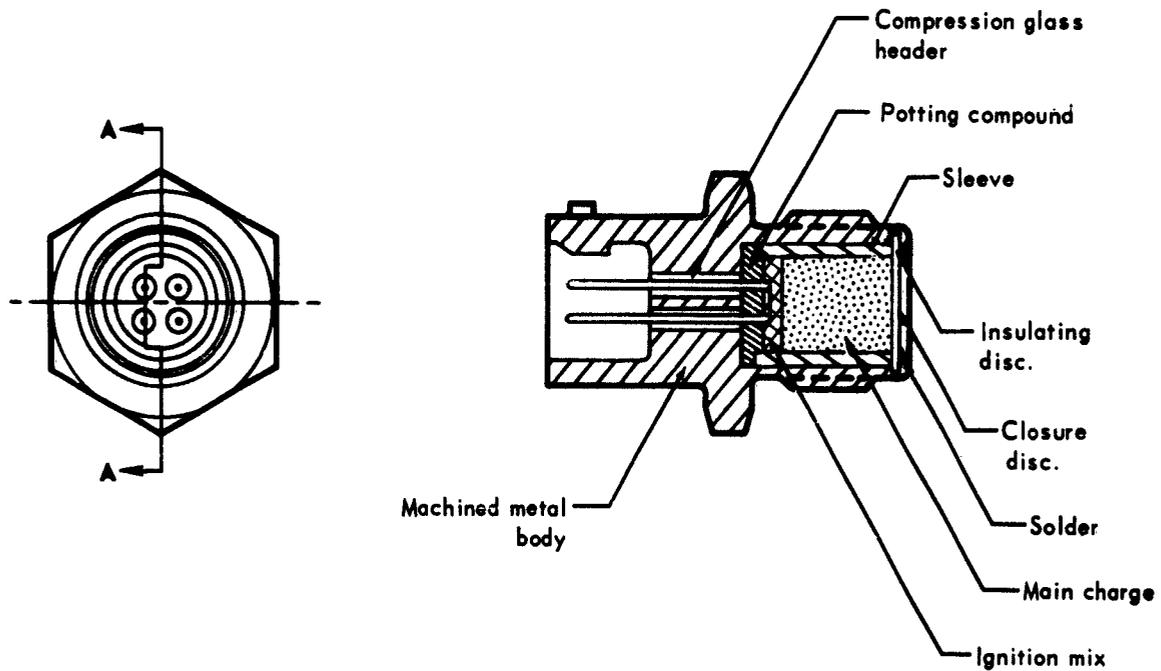
FIGURE 23 — BASIC INITIATOR TYPES

o   Weight limitations

o   Installation - accessibility and check-out

o   Economic considerations

Because of the more consistent performance characteristics, the wire bridge
is the most commonly used ignition method. Selection of the bridgewire
material is based on the energy input requirements, compatibility of the
wire with the chemicals in contact with the wire, and the temperature re-
quirements.

When the bridgewire temperature is increased by the application of increas-
ing firing energy, heat starts to transfer from the bridgewire to the pyro-
technic or explosive mix surrounding the bridgewire. This condition con-
tinues until the autoignition temperature of the mix is reached. If, however,
this rate of heat loss from the bridgewire equals the rate at which energy
is applied, at a temperature below the autoignition point, then a "no fire"
condition is achieved. For many ignition materials there is also a range
of "dudding" current, where a "no fire" occurs, but where the generated
temperature causes deterioration of the ignition mix, rendering the iniator
inoperative.

(d) Present Requirements

With the advent of the space age and the increased use of electro-explosive
devices (EED), there also was a considerable change in the complexity of
the electronics field. This included considerable increase in power of
such items as electrical controls, radar, and continuous wave carrier sig-
nals. As a result, a number of spurious firings of EED's through the pick-
up of extraneous currents and voltage have been reported. This resulted
in the establishment of a set of safety criteria by the USAF. The prin-
ciple feature of this criteria was the now well-known 1-amp, 1-watt for
five minutes requirement. This stated that the no-fire current shall not
be less than 1 amp as the result of the application of a direct current
for five minutes, no-fire power shall not be less than 1 watt as the re-
sult of the application of direct power for five minutes. Both requirements
must be met without the use of external shunts.

(e) Contemporary Designs

One method initially advanced and tested to meet the new requirements was
to place a resistor within the cartridge in series between each pin and
its side of the bridge, or to use a resistor as shunt. These methods did
not receive USAF approval because of the indirect method of meeting the
requirements. After considerable research, industry eventually succeeded
in meeting the requirements. The most popular method is the use of a metal/
oxidant-type mixture pressed against a flush-mounted bridgewire, usually
about one ohm resistance. This type of composition has a relatively high
autoignition temperature with a good thermal conductivity, permitting heat
to be transferred away from the interface of the bridgewire and the mix.
A typical design for an igniter or power cartridge is shown in Figure 24.
Figure 25 shows a similar arrangement, but for a detonator with a tip type
output.

Closure Disc

Insulating Disc

Projection or
Stitch Weld

Alternative End Closure

Metallized Ceramic Header

Pyrotechnic Pressed Load

Insulating Disc

Insulating Disc

Closure Disc

Solder Seal

Ignition or Propellant Mix

Sleeve

Compression Glass

First Fire Mix
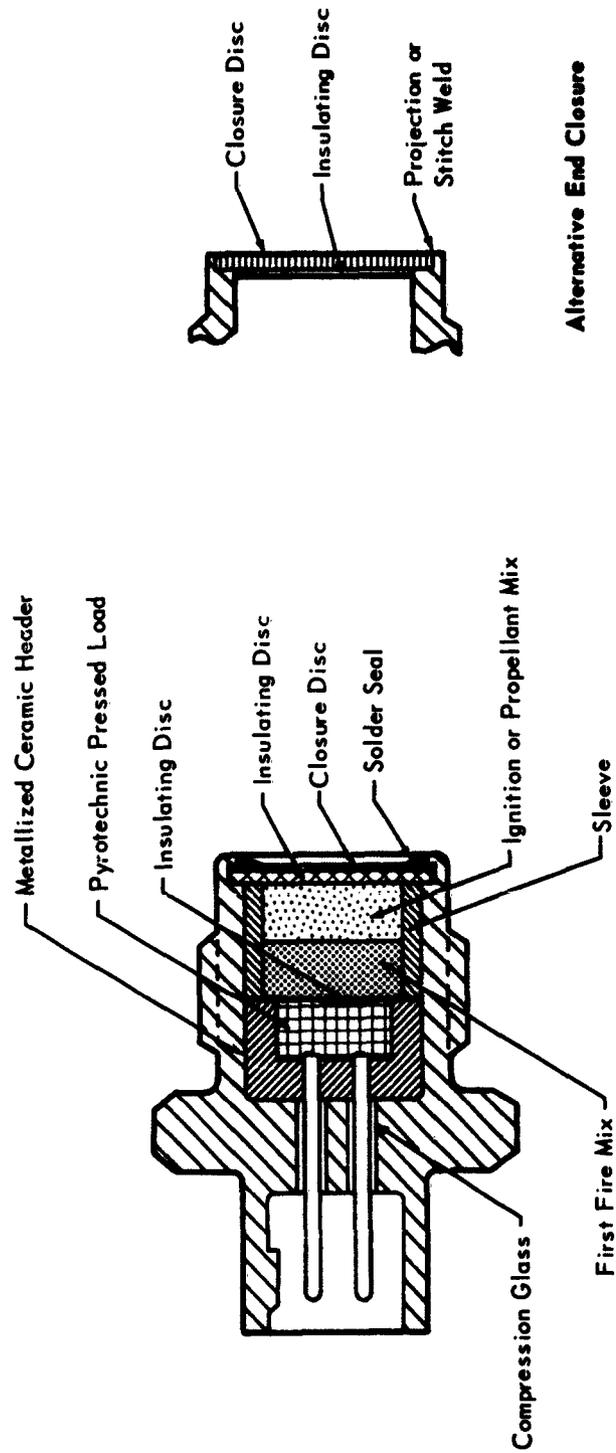
**FIGURE 24 – TYPICAL 1 AMP, 1 WATT NO-FIRE,
IGNITER OR POWER CARTRIDGE**

Pressed Pyrotechnic Load —

Metallized Ceramic Header —

Compression Glass —

Sleeve

Prime Explosive

Projection or Stitch Weld

Explosive Output Charge

Drawn or Impacted Cup

Insulating Disc
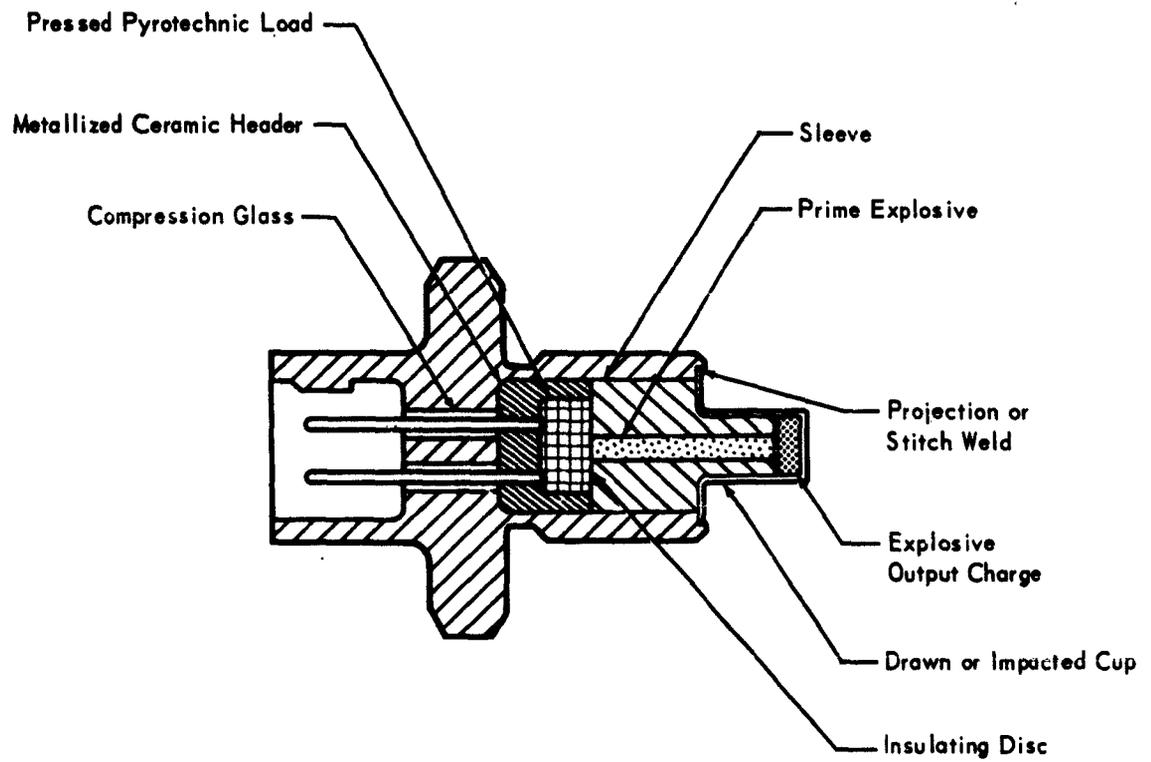
FIGURE 25 – TYPICAL FOR 1 AMP, 1 WATT NO-FIRE
DETONATOR WITH TIP TYPE OUTPUT

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An additional advantage to this design is that by using a metal/oxidant ignition mix, reliability of ignition of the next increment is improved. In the case of squibs this will be another pyrotechnic increment, or in the case of detonators it will be a prime explosive increment such as lead azide. The reason for improved reliability at this interface is due to the particular characteristics of the metal/oxidant-type compositions where heat transfer occurs rather than an explosive force. The reaction is nondetonating and creates large amounts of contained heat in the form of solid, fast moving particles. This combination provides excellent ignition transfer between increments. This is particularly true where a slight air gap is designed between the metal/oxidant pressed load and the next increment.

Air gaps generally are only necessary when the size of the initiator is small and therefore the ability of heat to be dissipated from the pyrotechnic pressed load mix is limited. This is a particularly critical consideration when the second increment is a prime explosive. In general, an insulating disc, possibly mica or Mylar, placed between these two increments will provide the necessary thermal insulation. Further, this disc helps meet the voltage breakdown specifications now demanded of the modern EED. Typical dielectric performance requirements are 1000 VAC at 60 cps applied pin-to-pin and pin-to-case for one minute duration with no arc-over, breakdown or transient increase in leakage current.

In the selection of materials to be used in headers, consideration must be made of both the operating pressure and temperature of the unit itself, and the system to which it is attached. As an example of some of the materials available to the designer, compression glass softens at $1250^{\circ}F$ and is capable of withstanding at least 10,000 psi. Some ceramics have operating temperatures as low as $700^{\circ}F$ but are capable of withstanding 20,000 psi, while others can operate as high as $2900^{\circ}F$ and withstand 13,000 psi.

In order to meet the wide variety of internal operating pressures, the designer has the option of sealing all the pins in a single header, sealing each pin individually, or of using a backed-up single header design. Examples of these designs are shown in Figure 26. Proper selection of header materials, therefore, and the use of the optimum design, can eliminate the oft-encountered problem of pin blow-back during operation of the EED.

Another critical area of design is the final closure seal. A commonly used technique is to roll crimp the body over a metal disc and then seal the crimp by induction soldering the unit. The explosive or pyrotechnic mix below this closure disc must be protected by an insulating disc to prevent accidental autoignition of the mix during this soldering operation. A more recent sealing technique is the use of projection welding, which does not elevate the temperature of the closure area more than a few degrees during the sealing operation. Both of these techniques are considered to be hermetic seals, but neither is completely perfect. Therefore, it is normal to establish a maximum leakage rate for a seal and, in general, this should be less than 10^{-6} standard cc's of helium per second.

With the advent of requirements for high operating temperatures, a word of caution must be given to the designer who might wish to choose one of the

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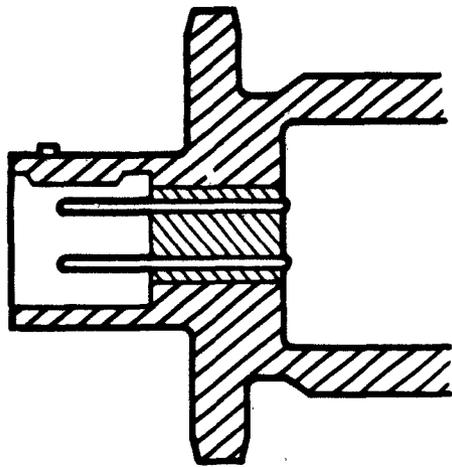
(a) Single Header Design
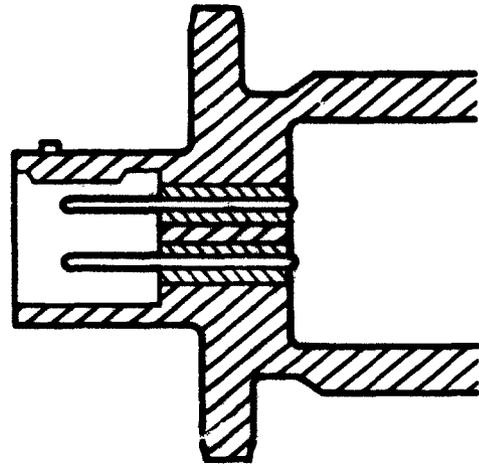
(b) Individual Pin Design
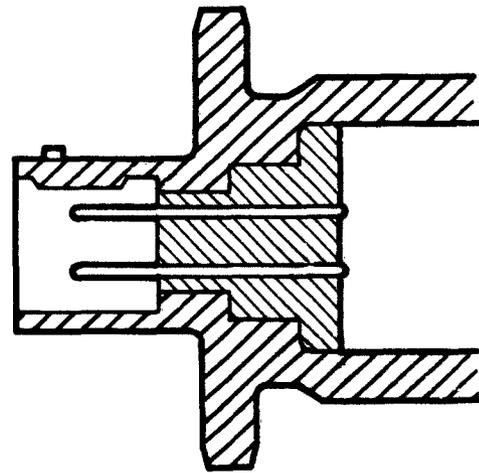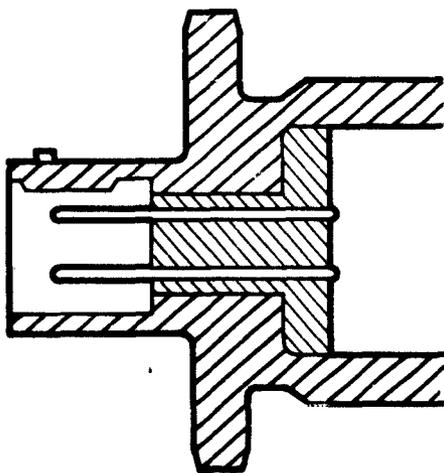
(c) Backed-up or Shouldered Design
Alternative Methods

FIGURE 26   CONNECTOR-TYPE HEADER DESIGNS

several high-temperature resistant high or secondary explosives. The caution is in the area of compatibility. Lead azide, for example, is not compatible with a number of new organic explosives, and may very well be incompatible with others of the high-temperature explosives.

(f) Design Criteria-Electric Initiators

The following operational requirements are considered to be the optimum design criteria for the electric initiators (both squibs and detonators) to be used in the separation and severance system. In addition, the requirements listed below will apply to all other electric initiators used throughout the crew escape system.

o   The design shall incorporate two independent and redundant electrical circuits. Each circuit shall be independent of, and insulated from, the cartridge body.

o   The design shall be such that it will not fire when 1.0 ampere is applied to either circuit or simultaneously to both circuits for five minutes at 70°F.

o   The design of the initiator shall be such that it will not fire when 1 watt is applied to either circuit or simultaneously to both for five minutes at 70°F.

o   The design of the initiator shall be such that after passing the no-fire test, Paragraphs 2 and 3 above, the cartridges shall fire within 20 milliseconds when five amperes is applied to either circuit. The units that have not been subjected to the no-fire test shall be capable of functioning within 10 milliseconds after five amperes is applied to either circuit or both circuits.

o   The resistance of each bridge circuit shall be 1.0 ± .1 ohm.

o   The design of the unit shall be such as to prevent the possibility of inadvertent firing due to transient currents and static charges.

o   The detonator shall be capable of initiating the standard SMDC booster tip with a reliability compatible with the overall system requirements, but in no event less than .9999 at an 80 per cent confidence level.

o   The geometry of the detonator output tip shall be identical to that of the SMDC booster tip. (This allows use of the initiation data available from the SMDC tip tests, and vice versa.)

2.2.3.2 Stimulus Transfer

There are available three basic methods by which to transfer the primary initiation stimulus to each PAD associated with the separation system. These are gas, electric, and explosive. A completely mechanical system was given no consideration due to the obvious weight penalty involved. Of the three mentioned above, the gas stimulus method is not considered capable of fulfilling the design requirements. This conclusion is based primarily on the belief that it would be

necessary to incorporate intermediate booster charges in the gas transmission lines with a resultant loss of reliability and weight penalty.

Of the two remaining methods, the explosive stimulus technique is considered the best choice for use within individual subsystems where a number of functions are to be initiated without interposed delays. The basis for the elimination of a complete electrical system has to do primarily with the problem of simultaneity. For example, assuming the use of individual electric initiators on each of six different PAD, it is possible to visualize an early/late firing condition which could induce undesirable performance of an overall subsystem. Such a condition might exist due to a "hang fire" or perhaps to nothing more than large variations in the initiator's operating times.

Another major problem area related to the purely electrical system has to do with the power required to fire a number of units simultaneously. Assuming the use of redundant initiators on each device, along with a five-ampere firing requirement, a total firing energy for the separation system alone of 100 amperes would be required. To this must be added the current required by the other subsystems being initiated simultaneously. The fulfillment of such a requirement is not considered practical from the standpoint of performance, weight, or reliability.

Within most subsystems of the study vehicle, the explosive stimulus will be conveyed by mild detonating cord (MDC). Since it is desirable to contain the resultant MDC blast energy to protect against structural damage, it is necessary to select the smallest practical explosive load. Although such a selection is almost completely dictated by reliability requirements, the weight of the cord, confinement media, and hardware associated with installation, must also receive prime attention. The inevitable problems of general handling and installation are, in addition, of extreme importance. Considering the above requirements, a nominal core load of three grain per foot was chosen for the separation subsystem application. There is a great deal yet to be learned about the new high-temperature resistant explosives discussed in Part I of this report. Nevertheless, there is sufficient data to establish that at least one of these, hereafter designated as HTE (high-temperature explosive), will meet the requirements of the applications at hand. HTE has been selected on the basis of excellent sensitivity, thermal stability, and power output. In addition, a number of preliminary screening tests on HTE-type mild detonating cord have been performed, the results of which are quite encouraging.

As has been previously explained, most PAD will be located in areas where the limitations of other equipment, such as electronics, will dictate the maximum allowable temperature to be experienced. In these areas, such as on the aft bulkhead of the capsule, higher temperatures, in the 400-500°F region, will be encountered. Here the high-temperature type, such as HTE, is essential.

To avoid the possibility of mixup of components, it was decided to use the same type of SMDC, having an explosive core of HTE throughout the system. This will also permit an improved determination of reliability, through a greater amount of available test data, and avoid the costs of a redundant development and proof-test program.

Containment of the MDC blast energy has generally been dealt with in two ways. In order to differentiate between the two approaches, they shall arbitrarily be

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referred to herein as confined mild detonating cord (CMDC) and shielded mild detonating cord (SMDC). The CMDC-type design usually consists of the basic MDC overwrapped with alternating layers of a fibrous yarn material such as rayon or fiberglass and some reasonably tenacious plastic such as polyethylene. In some cases the outer wrap consists of a heavy, woven Fiberglas fabric. One of the most important advantages of the CMDC is its flexibility. Tests on particular types of CMDC have shown it capable of reliably propagating detonation through tight knots or similar kinks, loops, or twists that may be inadvertently introduced into the assembly during installation. In addition to total system application, the CMDC has found wide acceptance for component designs requiring a mechanically flexible initiation input. A typical CMDC hookup is shown in Figure 27. The particular system depicted incorporates the added advantage of quick disconnects which would appear to offer a substantial savings in installation time.

Shielded mild detonating cord (SMDC) consists of the basic metal sheathed explosive, covered with a thin fibrous overbraid, all contained in a thin wall stainless steel tube. Although the basic design weighs approximately the same per unit length as CMDC, the total system weight of the tubing-housed SMDC is less than that for CMDC. This is true because the end fittings are considerably lighter, and because a greater number of brackets are required to maintain a reasonable degree of rigidity in the CMDC to resist vibration and offset whipping of the cord during detonation. Another advantage of SMDC is that it usually is smaller in diameter than CMDC, and consequently occupies less space in the vehicle. This could be of extreme importance in the design of a high density spacecraft. Also, there would appear to be somewhat of an advantage in the use of the SMDC at temperatures in excess of 400°F. However, this advantage could be overcome by the use of thermally stable plastics and fibrous wrapping in the CMDC design. Some users also have cited the large instantaneous growth of CMDC upon detonation as a disadvantage. However, the stainless steel tube associated with the SMDC also swells to a lesser extent, and therefore, allowance for this swelling is a design consideration for either configuration.

Regardless of the type of design used, it is necessary to terminate the stimulus at the points where it must perform its prime function of initiation. Normally this is accomplished through the use of an end fitting containing an explosive booster. The size and shape of the booster is primarily a function of the application. For any system, however, it is common to standardize the booster tip. Shown in Figure 28 is a typical SMDC section with attached boosters. As in the basic cord, HNS is also recommended for use in the booster tip. Based on the results of recent tests, a nominal load of one grain (65 milligrams) pressed to approximately 30,000 psi, is considered adequate to meet normal performance and reliability requirements.

(a) Junction Blocks

Junction blocks are inert fittings, closely resembling tubing fittings in appearance, which are used to hold SMDC or CMDC tips in such a position and proximity that cross-initiation, or stimulus transfer, takes place among the various SMDC lines led into the junction. They also are designed to contain the blast of the SMDC boosters contained in these tips and thus provide a sealed explosive system, both before and after firing. Junction blocks frequently are used to provide the type of redundant-path initiation

50
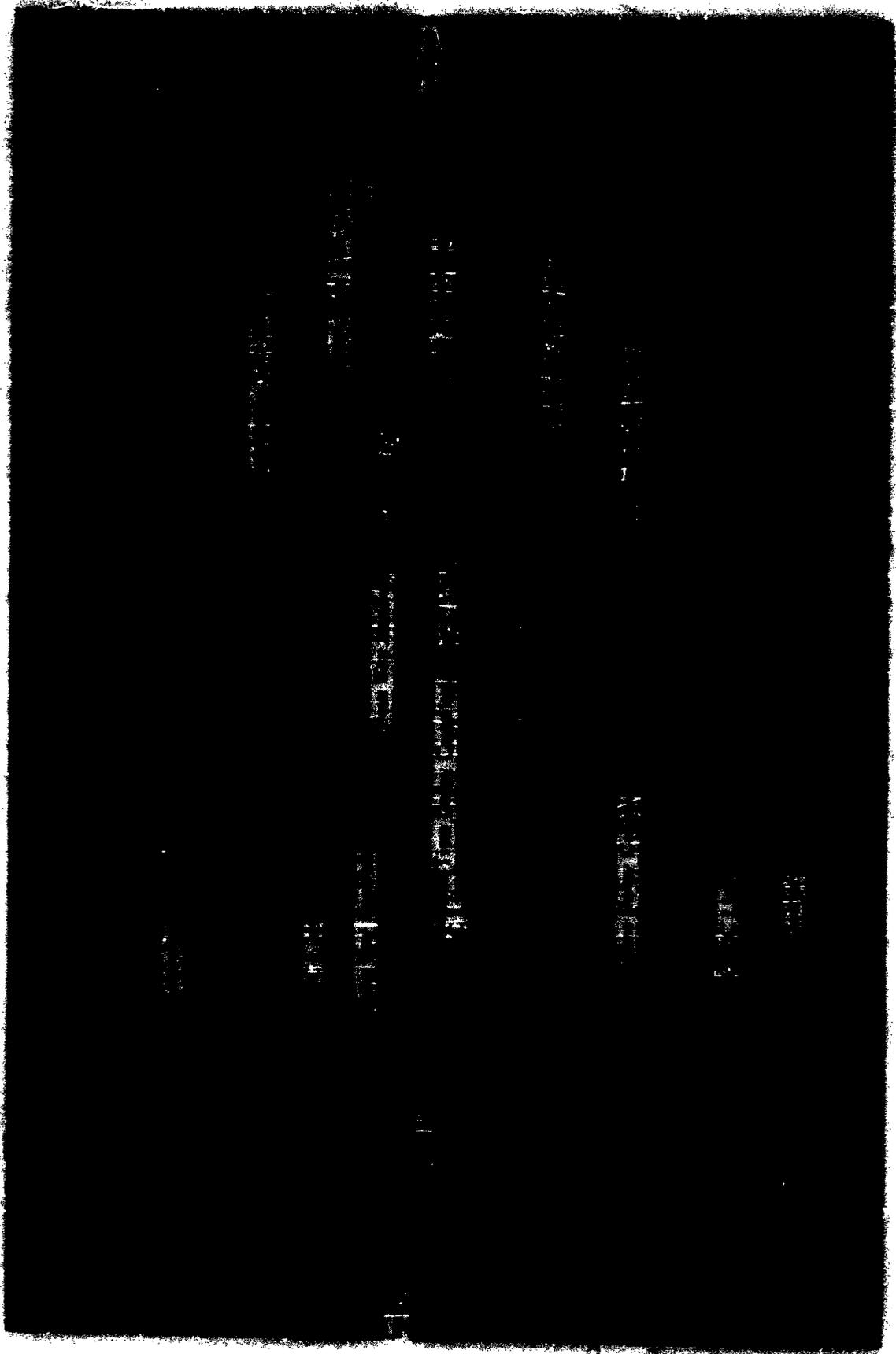
**FIGURE 27 TYPICAL CONFINED MILD DETONATING CORD (CMDC) HOOKUP**
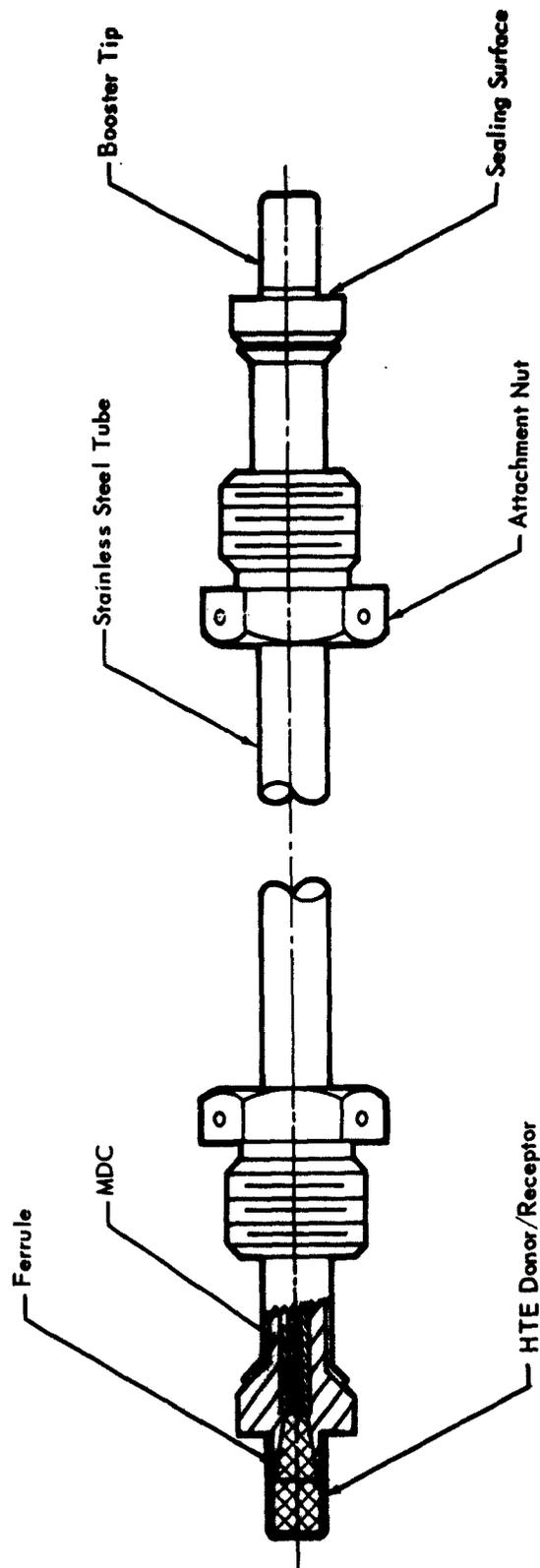
FIGURE 28   TYPICAL LENGTH OF SHIELDED MILD DETONATING CORD (SMDC)

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in components and subsystems discussed in Section 2.2.2, "Reliability." They also permit a degree of flexibility in the design of individual PAD and stimulus transfer networks where the incorporation of cross-over charges within the PAD would be geometrically impractical or would require excessive SMDC line lengths.

In the component and subsystem designs presented in this report there are currently no junction blocks required, the functions of interconnection and cross-initiation being accomplished either within the individual PAD or in the subsystem initiators. However, the subsystems shown are hypothetical in nature, and should this escape system ever be reduced to practice, it is likely that at some time the need for junction blocks would arise. Furthermore, they have, and will continue to have, application in MDC systems, and thus a discussion of them is warranted.

Although the use of junction blocks frequently permits considerably more PAD design flexibility than might otherwise be possible, indiscriminate and thoughtless application can actually reduce their effectiveness from the standpoint of reliability, weight, and even cost. Extreme care, therefore, should be exercised in the use of junction blocks.

With respect to design criteria, the most important aspect of junction block design is the ability to contain the blast energy of the SMDC boosters at the highest specified design temperature. In addition, distortion of the blocks should be kept to a minimum to offset post-fire gas leakage. This is particularly true for a junction block located in the cockpit area.

Shown in Figure 29 is a typical four-tip junction block. A similar design, Figure 30, which incorporates a receptor port for an electrically initiated detonator is typical of that used for the separation subsystem. Two and three-way junction blocks are shown in Figure 31. Should it be desired, an electric detonator could be installed in either of these two blocks for the purpose of primary initiation.

(b) Initiation of PAD from a SMDC Stimulus

In many applications, the output from the SMDC stimulus transfer is used to initiate a cartridge or propellant actuated device, rather than another high explosive element. In addition, in the interest of redundant initiation paths, it is also required that either of two SMDC output tips also cross-initiate the other tip entering the firing head of the device. This, then, calls for the equivalent of a 3-branch junction block where the of the legs is purely a "power take-off" or output branch, in which the high explosive energy is converted to sufficient mechanical energy to fire a conventional cartridge primer.

Investigation has shown that the shock wave and/or the fragments from the SMDC tips will reliably fire a percussion primer, if their directionality is properly controlled. Also, the blast pressure will drive a conventional firing pin of the piston-type to accomplish this function independent of directionality. However, a disc-type firing pin which is belled by the tip blast energy has been developed by McDonnell Aircraft Corporation, and has been shown to have numerous advantages.

SMDC

Mounting Holes

Booster Tip
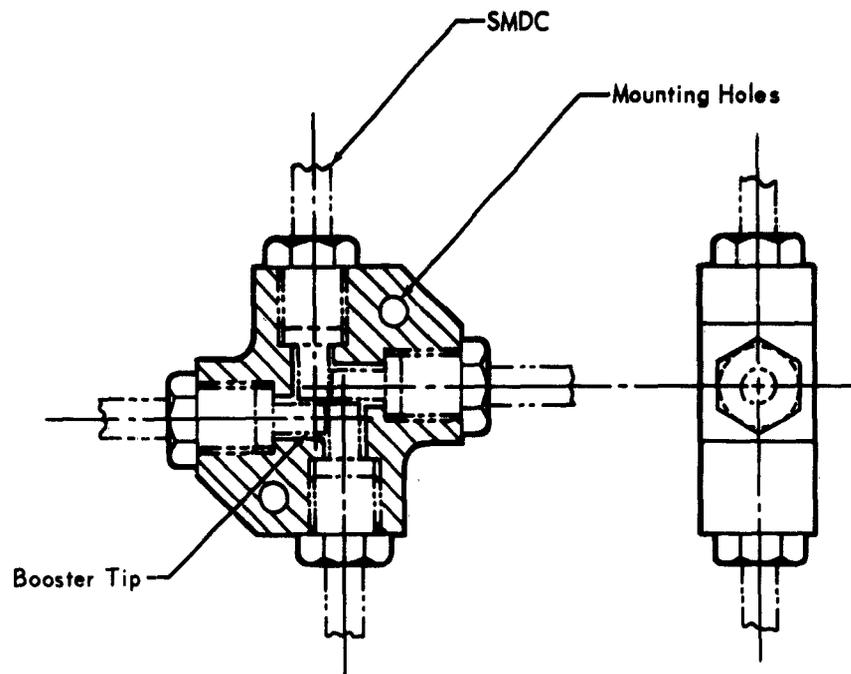
FIGURE 29 FOUR-TIP JUNCTION BLOCK

SMDC

Initiator (Detonator)

A

A

Seal

A – A

A – A
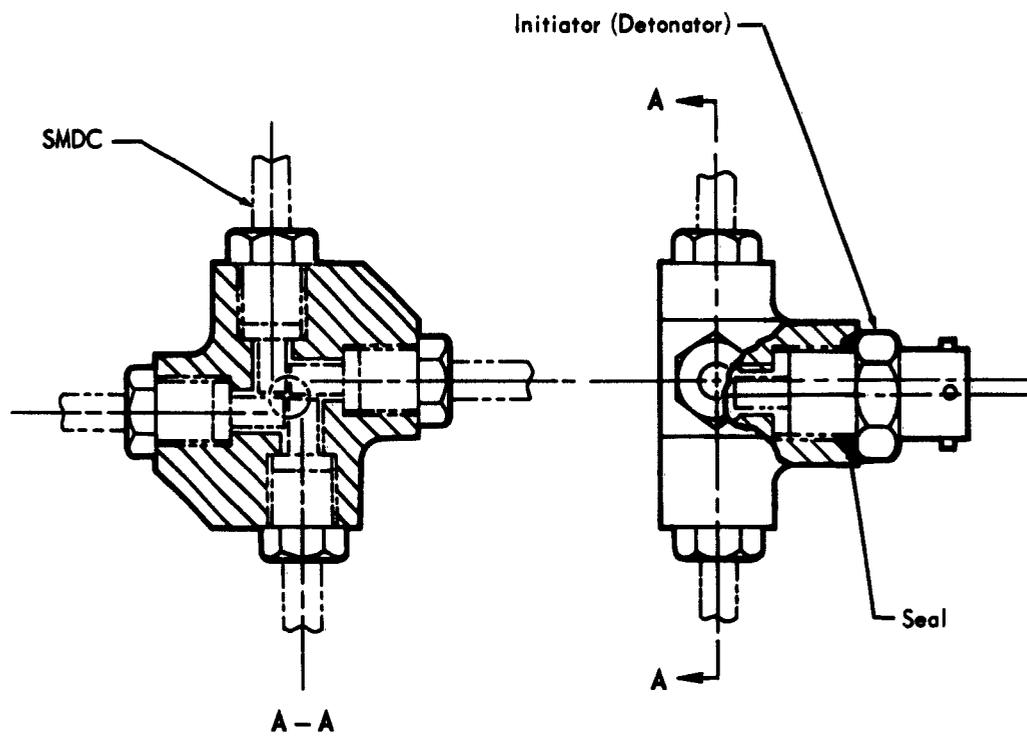
FIGURE 30   INITIATOR AND FOUR-TIP JUNCTION BLOCK

SMDC

Booster Tips

Possible
Electric Initiator
Location
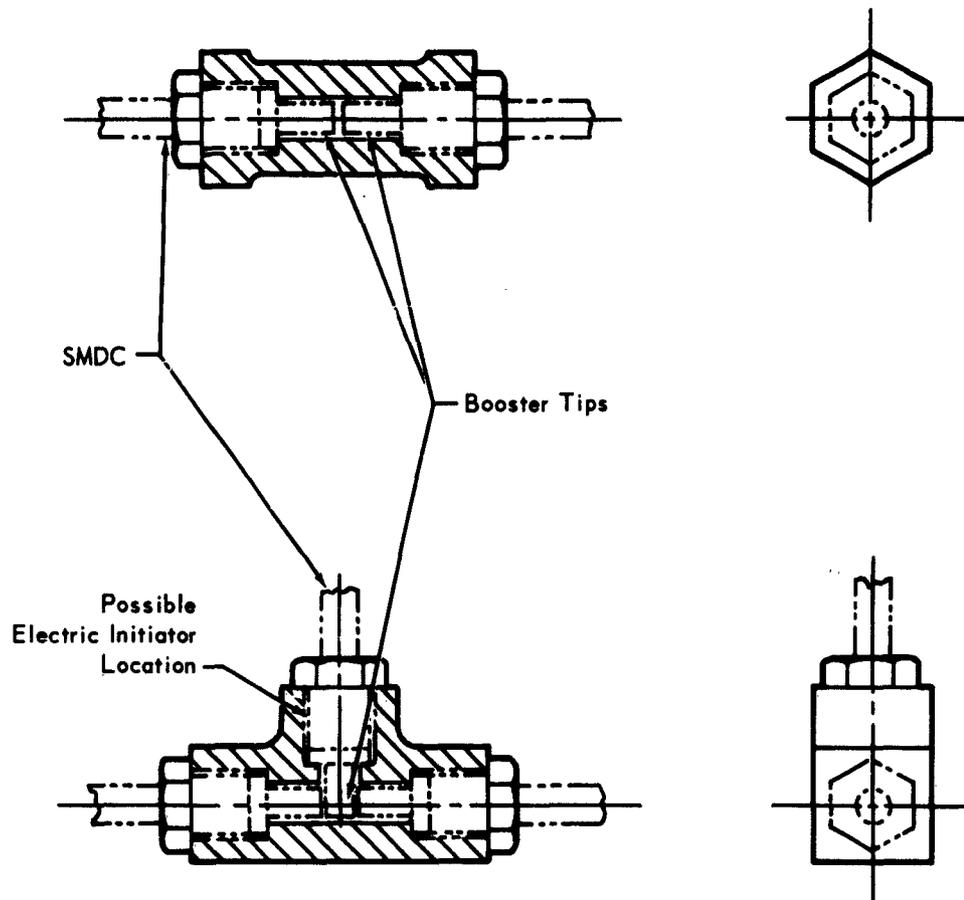
FIGURE 31   TWO- AND THREE-TIP JUNCTION BLOCKS

o   It is a rigid element, requiring definite distortion energy to acti-
    vate.

o   It is easy to seal against leakage in either direction.

o   After actuation, it provides a positive backup against primer blow-
    back.

o   It is very light and compact, requiring virtually no extra length in
    the unit.

o   There is little or no chance for misalignment, thus making a swivel
    and fitting practical and reliable.

Swivelling or adjustable end fittings are required on most SMDC-initiated
PAD so that the orientation of the input ports can be controlled. While
this would be desirable with any form of stimulus input, it is nearly es-
sential when the rigid SMDC is used. Two types of end fittings are shown
in Figure 32. One is truly swivelling, and shows several optional means
of providing the fitting retention. The other end fitting is adjustable
by removing layers from a laminated washer but is not a swivel device, and
therefore is not as convenient to use. Its advantage is that it is lighter
and more compact. Both types use the disc-type firing pin discussed above.

Henceforth in all applications of SMDC to cartridge initiation, either of
the end fittings (firing heads) shown will be assumed.
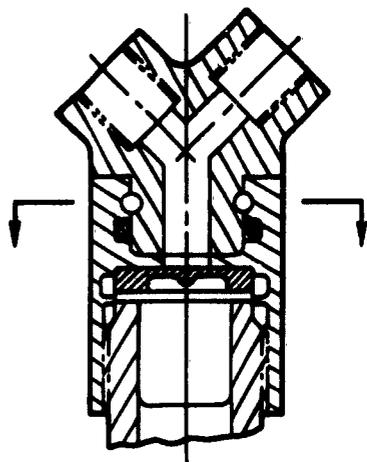
(a) Swivel Head
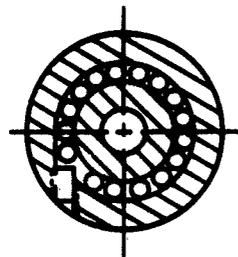
Ball Retainer
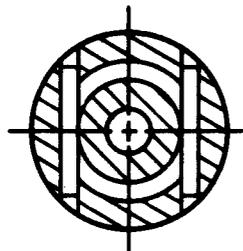
Roll Pin Retainer
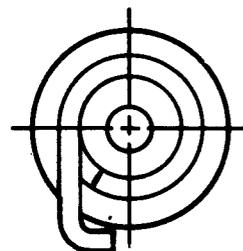
Wire Retainer

Laminated Washer
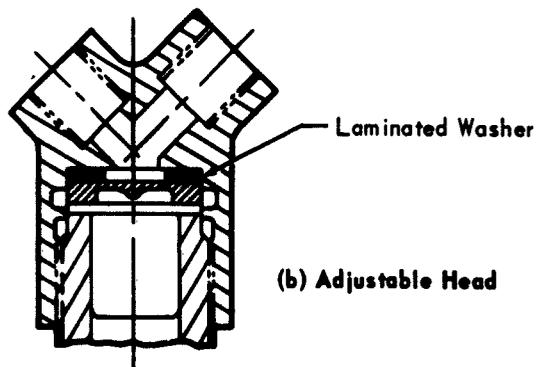
(b) Adjustable Head

FIGURE 32   TYPICAL SMDC / PRIMER END FITTINGS

2.2.3.3 Pyrotechnic Delays

The advantages of pyrotechnic delays are their ability to operate over a wide temperature range (-100°F to +200°F), operate under very high impact loads, take up very little volume, and be relatively low cost items. Over the ambient temperature range of -65° to +165°F, and under optimum conditions, a delay burning within 20 seconds should not vary more than ±12 to 13 per cent. Under less favorable conditions, such as a crowded design or over the wider temperature range, -65°F to +200°F, these limits may well increase to as much as ± 20 per cent.

Pyrotechnic delays are usually prepared by pressing at quite high loading pressures (30,000 psi or higher) one of many available delay compositions into a column. Upon ignition at one end of the column, the pyrotechnic composition burns down the column and ignites the next element of the train. The length of the column and the burning rate of the composition determine the overall delay time.

The pyrotechnic delay compositions most generally used are of the "gasless" type. These are physical binary or tertiary mixtures of one fuel with one or two oxidizing agents. Since the reaction of the mixture upon burning produces a solid slag and very little gas (up to 10 ml/gram of composition, at S.T.P.), they are called "gasless" delay compositions. Even so, it usually is necessary to provide venting of the delay column in order to prevent erratic burning times as a result of any pressure buildup. The venting can be to the atmosphere, but it is more preferable to vent into a small internal expansion chamber, particularly if the delay element is to be used for low pressure applications. Gasless type compositions become difficult to ignite when the absolute pressure is below 0.3 psia.

Relatively recent research work on the behavior of delay systems has produced evidence that may be a major contributing factor towards the problem of reproducibility. This is the significant shortening ("anticipatory effect") of the delay times when a terminal or relay charge is placed directly at the end of the delay column. It appears that this thermally sensitive material is ignited by hot gases from the reaction zone preceding the actual reaction front. In effect, a portion of the delay column is bypassed by these hot gases permeating through pressed pyrotechnic composition. There is some indication that the faster the burning rate of the delay composition, the less the anticipatory effect.

There are several basic types of gasless delay powers available to the designer, paramount of which are the silicon, zirconium-nickel alloy, boron, manganese, and the tungsten-type compositions. The former was developed by the U.S. Army Chemical Corps, and has been used in a variety of ordnance devices. The silicon compositions exhibit a good slag retention capability, which is an important factor in maintaining uniform burning of the delay. In addition, they have a low temperature coefficient. Their principal disadvantage is that silicon is poorly standardized from a lot-to-lot basis, and therefore reproducibility is difficult. Further, the compositions are susceptible to moisture.

The zirconium-nickel alloy-type compositions are similarly affected by moisture, and, in addition, exhibit poor slag retention characteristics. Like the silicon compositions they have a relatively low temperature coefficient. Boron type delays, which are usually formulations of boron and barium chromate, also are well-known as an ignition material, possess a poor slag-retention capability, and offer only a narrow reliable burning time range. In addition, very small variations in the boron content cause appreciable changes in the burning rate of the composition. These boron compositions also seem to be subject to aging until a stable plateau is reached. The reliable burning rate range is limited from 1/2 to 2 1/2 seconds per inch.

The tungsten-type powders, developed under Naval Ordnance Laboratory auspices, represent the most recent developments in delay compositions. In conjunction with barium chromate and potassium perchlorate, they are capable of from 1 to 48 seconds per inch burning rate. Because of substantial changes in the burning rate with very small changes in the percentage of tungsten powder above the 30-second/inch rate, extreme care must be exercised in the use of powders above this rate. Even so, these compositions tend to have a greater dispersion than most of the other delay powders available. A further problem that exists with this type of delay mix is that different lots of tungsten powder possessing the same physical characteristics often behave differently when formulated into a delay mix. Also, there is a supply problem in obtaining tungsten powder specifically suitable for delay compositions.

The manganese-type delay compositions, which consist of varying percentages of manganese powder, lead chromate, and barium chromate, probably are the best known and most reproducible of all the delay powders. Originally developed by the Naval Ordnance Laboratory, these compositions have a burning rate range from 2 to 13.5 seconds per inch, and further, this type of delay composition does exhibit good slag retention qualities. The manganese compositions have a certain susceptibility to moisture, and for a long time it was recommended that a tedious protection process for the manganese be followed; however, it has been demonstrated that this treatment process is unnecessary. With the proper preparation of the materials and the proper processing of the composition, moisture problems are only of academic interest, particularly since most delay designs provide complete sealing to the atmosphere.

Therefore, it is recommended that the manganese-type delay compositions be used wherever pyrotechnic delay trains are required.

(a) Delay Initiators

In several places in the study vehicle system, delay initiators having the standard SMDC tip output are required. In some instances, an electrical input is wanted; in others, dual SMDC inputs are specified. After weighing the various design factors involved, it was concluded that there is considerable merit in having a common delay element, incorporating an integral SMDC output tip, which is capable of accepting either type of input.

Such a delay element is shown in Figure 33c. The thread size on each end is identical, and is equal to that on one of the standard 1-Watt/1-amp squibs discussed in Section 2.2.3.1(f). Thus, by insertion of the standard squib, a complete "delay detonator" is obtained.

By use of a special SMDC-to-delay element adapter having the same thread size on the output end, and incorporating a primer/firing disc assembly as discussed in Section 2.2.3.2(b), the assembly is made into a SMDC/SMDC delay element.

The advantages in cost of manufacture, cost of qualification, and the gain in statistical test data (for verification of reliability) are obvious. Most delay units can be qualified by similarity.

Yet there is no advance in technology required. Every design feature required has already been made and tested, and most of the elements are already required for other applications.

(b) Design Criteria - Delay Initiators

In addition to the environmental requirements outlined in the Appendix the initiators must fulfill certain operational requirements. The most important of which are that:

o   The SMDC input delay initiators shall be designed for initiation by either of two standard SMDC booster tips.

o   The firing head shall be so designed that it accepts two SMDC end fittings, and that either tip will cross-initiate the other tip, as well as actuating the delay initiator.

o   The electrically fired delay initiators shall accept a standard 1-Watt/1-amp squib per Section 2.2.3.1(f).

o   The firing head shall provide an environmental seal for all components before and after actuation.

o   The delay time and tolerance of each initiator model shall meet the specified values for its individual application.

o   The output of the delay initiator shall be a standard SMDC tip, as previously defined.

o   The design shall be such that the input element and the delay element, once assembled, cannot be disassembled without destruction of the unit.

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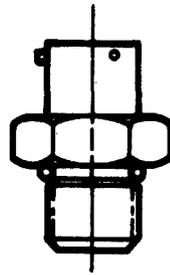
(a) Standard Squib
(1 Watt - 1 Amp)
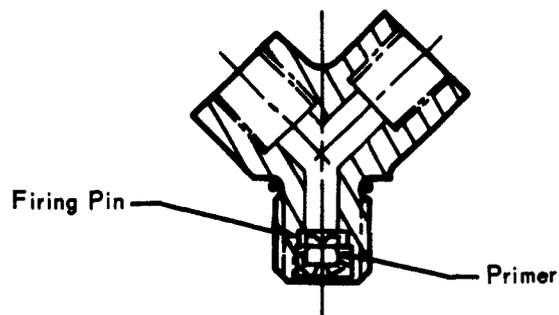
(b) MDF-to-Delay Element Adapter
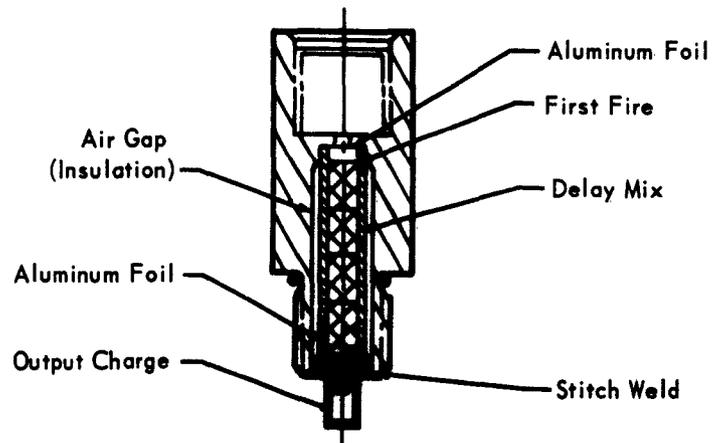
(c) Delay Element

FIGURE 33   DELAY INITIATOR ELEMENT AND ALTERNATE
INITIATING ELEMENTS

o   The design shall be such that the incoming leads, whether
    electrical or SMDC stimulus transfer lines, can be connected and
    removed without the use of special tools. Similarly, the delay
    initiator assembly shall be capable of installation or removal
    from the system without the use of special tools.

o   The design shall be such that the shock produced by the SMDC tips
    shall not disturb the delay train so as to produce excessive
    variations in delay times.

2.2.3.4 Pyrotechnic Switches

A large number of instantaneous and delay switches are required in the escape and recovery system. Some consideration was given to the use of latching relays for this purpose, but analysis led to the conclusion that the use of pyrotechnic switches could provide more reliability with less weight.

At first, consideration was given to the use of a special switch adapter which would mate directly with standard electrical and SMDC initiators. These could be made to have standard electrical connector (MS) outputs. However, further study showed that the chief use of these would be in remote locations, not amenable to incorporation into "black boxes."

In the specific system covered in this study, however, virtually all switches, both instantaneous and delay, will be incorporated into circuits which will already require black box construction. Thus, neither shielded leads nor individual electrical connectors are required. This makes possible the use of existing pyrotechnic switches of established, very high reliability, whose compactness and weight are near optimum.

An excellent example of such switches is shown in Figure 34a. This shows a 2-pole, 1-amp/1-Watt switch, the use of which permits the application of redundant circuitry in a manner similar to that discussed for SMDC in Section 2.2.2. Figure 34b shows a modification of a 1-amp/1-Watt switch which is essentially the same as that of Figure 34a, except that extra protection against RF radiation is afforded by means of a ferrite plug which attenuates radio frequencies up to 400 megacycles.

The above switches are both instantaneous. The switches also are available in delays up to 30 seconds. All dimensions are nominally the same except that the overall length increases by approximately .1 inch per second.

Other makes are available, but those shown were selected as representative examples because they incorporate all the features which would be desired for this application.

Figure 35 shows, schematically, how dual 2-pole switches would be used with 2 dual bridge initiators for maximum system reliability. As has been previously stated, all electrical systems shown in the general schematic drawing should incorporate this dual circuitry. However, it was not shown on the schematic so that maximum clarity could be maintained.

(a) Design Criteria - Pyrotechnic Switches

In addition to the environmental criteria shown in the Appendix, the following design criteria should apply to all pyrotechnic switches:

o   All switch initiators shall be of the 1-watt/1-amp type, having a nominal bridgewire resistance of 1 ohm.

2-POLE, INSTANTANEOUS PYROTECHNIC SWITCHES

.170

.090 — .160

.275

.040 x .080

Flattened & Pierced Pins
(Optional)

1.116

.175 Typ.

.723

.040 Dia.
Typ.

.250

.375

.375

2 Times
Size
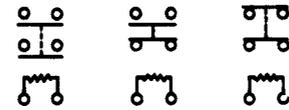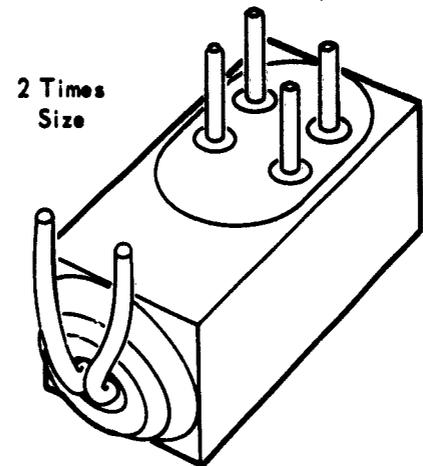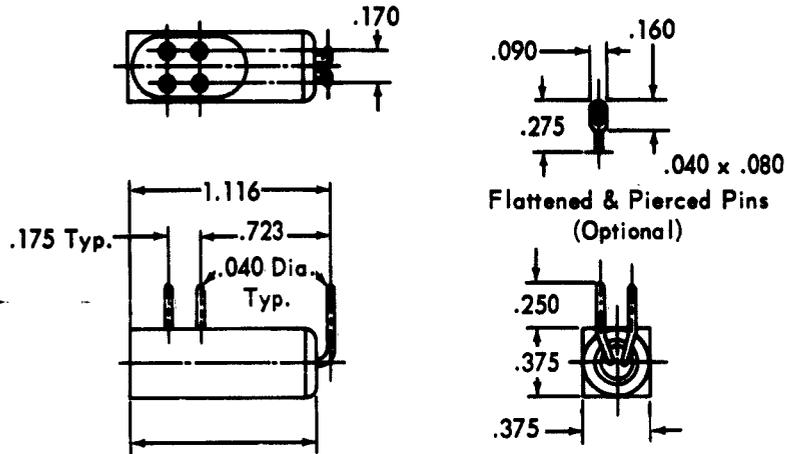
Typical Contact Arrangements

1-WATT/1-AMP PYROTECHNIC SWITCHES WITH ADDED R.F. PROTECTION

Ferrite Plug

Alumina Ring

Shield

Actual Size

A

.175 Typ.

1.170

.040 Dia.
Typ.

B

.250

.375

.375
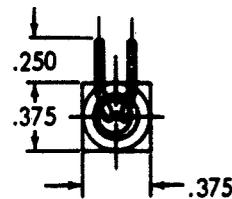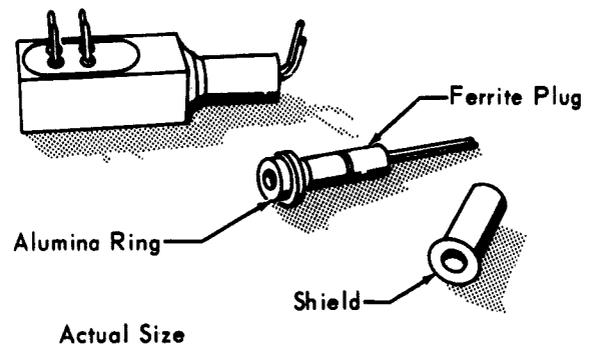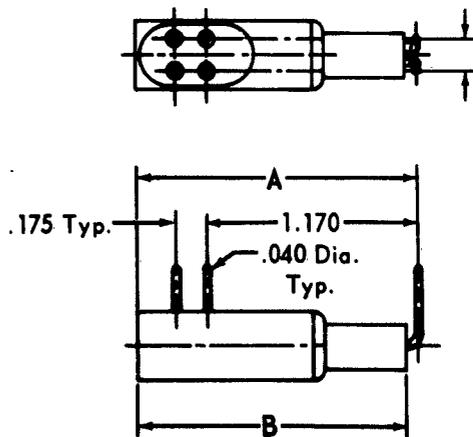
	A	B
2-pole:	1.565	1.495
4-pole:	1.917	1.847
6-pole:	2.267	2.197
8-pole:	2.617	2.547

FIGURE 34   MULTI-POLE PYROTECHNIC SWITCHES
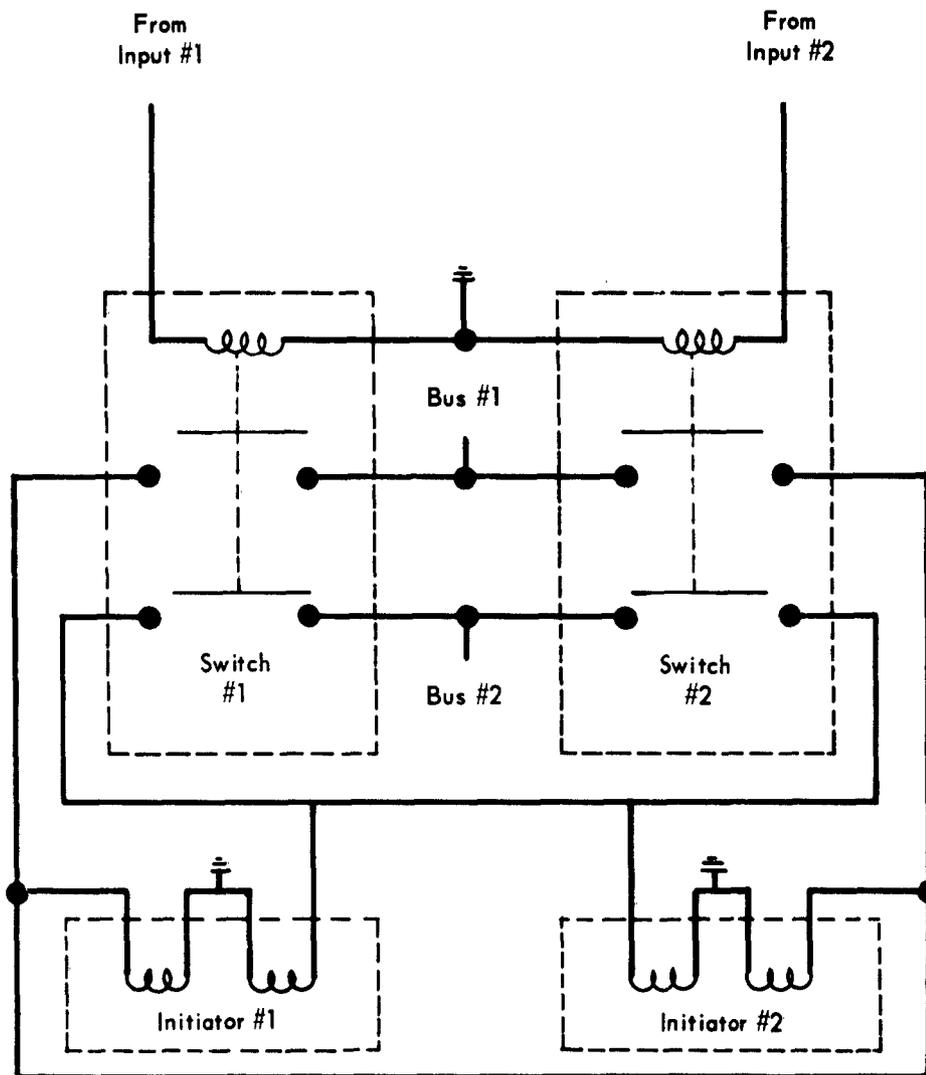
FIGURE 35 SCHEMATIC DIAGRAM SHOWING USE OF DUAL 2-POLE PYROTECHNIC SWITCHES WITH
2 DUAL-BRIDGE INITIATORS FOR MAXIMUM RELIABILITY

66

o   Switch contacts shall be capable of conducting a minimum of 30
    amperes at 28 volts d.c. for a minimum of 10 seconds.

o   Actuation time for instantaneous switches shall not exceed .020
    second. Tolerances on delay times for delay switches shall be
    compatible with performance requirements for the escape and
    recovery system.

o   Resistance between isolated terminals and between terminals and
    case, prior to firing, shall be a minimum of 50 megohms.

o   Resistance between isolated terminals, and between terminals and
    case, after firing, shall be a minimum of 10 megohms.

o   Resistance between closed terminals shall be less than .01 ohm,
    whether such terminals are closed before or after firing.

o   If the bridgewire circuit of the switch initiator has a resistance
    of less than 10,000 ohms after firing, an extra set of normally
    closed contacts shall be used, and the bridgewire circuit shall
    be routed through said contacts, so that upon switch actuation the
    firing circuit is interrupted.

2.3 Subsystem Pad Selection

2.3.1 Separation Subsystem

2.3.1.1 General

Immediately upon receipt of an abort signal the escape system will be initiated either by action of the astronaut or through a ground control command link. Regardless of the abort mode, the separation system will be one of the first items initiated. In some instances simultaneous firings will exist between the separation devices, tower rocket, posigrade rockets, landing abort and retro grade rockets. For any case, however, the successful operation of the separation system is the important first step in the escape sequence and must perform with an uncommonly high degree of reliability.

Shown in Figure 36 is the schematic for a separation subsystem which is considered applicable to the vehicle in question. Because of the theoretical nature of the study, it is not possible to determine the exact nature of each PAD function. Obviously, however, it will be necessary to provide for structural separation in addition to the severance/ disconnect of a number of tubes, wire bundles, and possibly control cables. Consequently, two cable cutting and two tubing disconnect functions have been incorporated in the separation system. The number of such operations has been established on a random basis, and are primarily intended to aid the presentation of the conceptual designs. All separation system PAD will be mounted directly to or in the area of the crew escape module's aft bulkhead.

2.3.1.2 Cable Cutters

There are three basic techniques by which it is possible to cut or disconnect cables pyrotechnically. These techniques are encompassed in guillotines, shaped charge cutters, and quick disconnect devices.

The guillotine is a relatively simple device which contains a piston, modified, so that its leading edge is shaped to either a chisel or round blade configuration. The cable to be cut is placed through a hole in the body, and lies against an anvil attached to the end of the guillotine body. When a propellant charge is ignited, the piston blade or cutter is driven forward, severing the cable and coming to rest against the anvil. The initiation system is quite flexible and the guillotines can be designed for initiation mechanically through a primer, electrically with an electric initiator, or through an MDF stimulus.

As mentioned above, the piston or cutter may be designed to have either a chisel or round blade. The latter normally is used only for reefing line cutters where the cable to be cut has a tendency to fray. The circular blade, therefore, cuts the line in two places, thereby increasing the reliability of cutting such materials as nylon. This design is not

Initiators

Explosive Bolts

Tubing Disconnect

Tubing Cutter

Cable Cutter

Cable Cutter

— — — — SMDC

———— Electrical
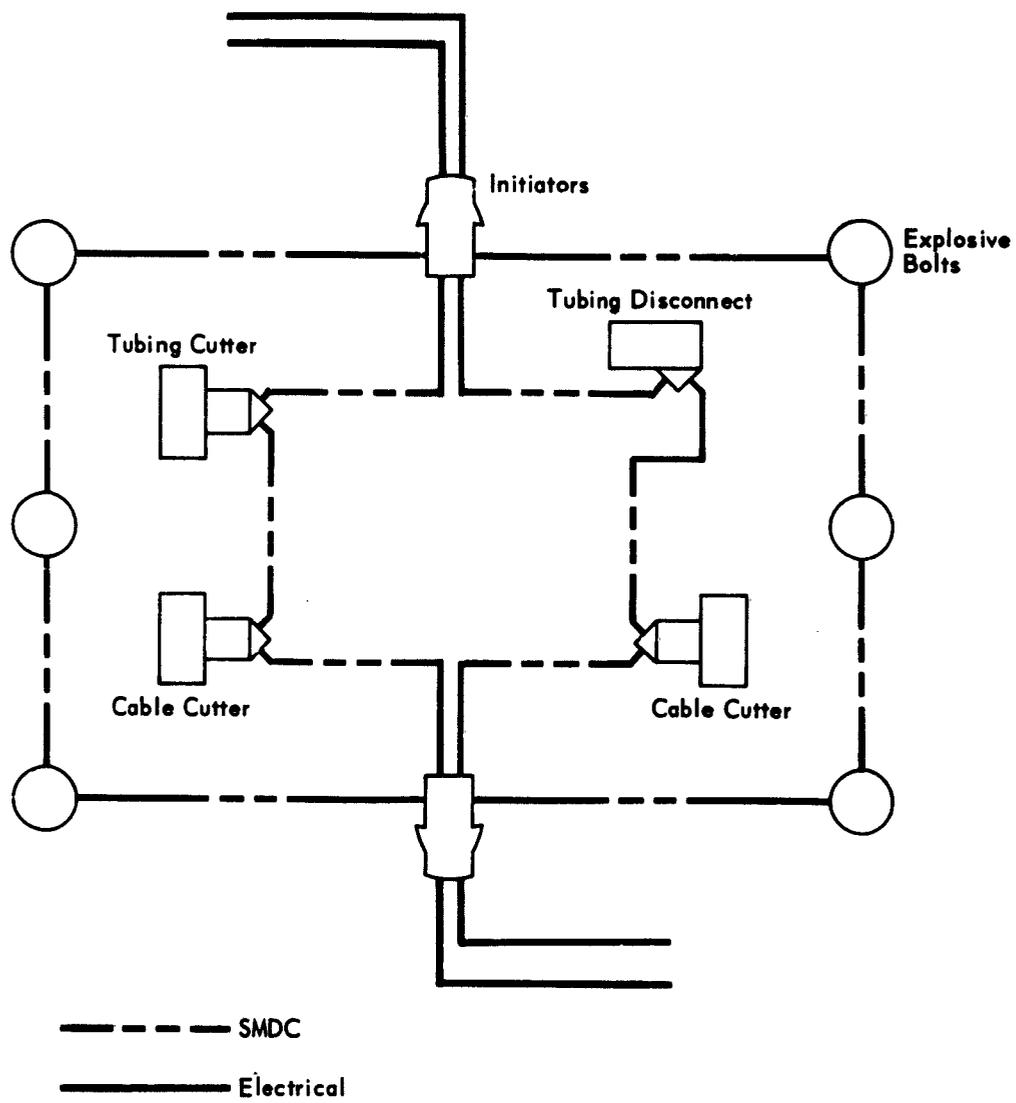
FIGURE 36   SEPARATION SUBSYSTEM

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suitable, however, where cables, possibly armored, have to be severed. In this case, a chisel blade design is desirable because all the available kinetic energy can be delivered to a single cutting surface. The principle advantages to the guillotine method of severance are the comparative compactness of the devices, their cleanliness, and their ability to cut either electrical or control cables. The principal disadvantage is the possible "smearing" action of the cutter blade when cutting electrical wire bundles, and the resulting between-lead shorting.

Shaped charge cutters also are relatively simple devices, in which flexible linear shaped (FLSC) serves the same function as the cutter blade of the guillotine. In this type of device the FLSC is potted into a metal holder which is then clamped over the cables to be severed. Initiation can be by any of the modes discussed for the guillotines. For improved reliability it is sometimes desirable to cut in opposing directions, but under these circumstances the FLSC is not usually positioned so that it directly faces itself; rather, it is offset and therefore produces independent cuts. The principle advantage to this technique of severance is the ability to cut quite long, narrow sections which permits the stacking, side-by-side, of many cables. The main disadvantage to the technique is the resulting blast effect and the consequent weight penalty necessary for adequate shielding to absorb this blast energy. Secondly, quite high core loading of the FLSC must be used if control cables are to be cut, which, of course, further increases the blast problem.

Finally, the quick disconnect device offers the third alternative. This requires the modification of multipin electrical connectors in such a manner that the firing of a gas generating or pressure cartridge initially unlocks the connectors and the residual pressure then forces them apart. The advantages of this type of system are that it is fast, reliable, and clean. The disadvantages are the space requirements necessary and the weight requirements when large numbers of wires have to be disconnected.

Based upon the above discussion, guillotines are recommended for use as cable cutters for the separation and severance system. The recommended design for a guillotine cable cutter is shown in Figure 37. Internal switching or dead-facing would be required in certain electrical cables.

(a) Design Criteria - Cable Cutters

The following operational requirements are considered to be optimum design criteria for the cable cutters (guillotine type) to be used in the separation and severance system.

o   The propellant cartridge for actuating the cutter blade shall be designed for ignition by means of a primer.

o   The design of the housing above the propellant cartridge shall be such as to provide two threaded ports to accept two SMDC tips.

MDC Tip Receptacle

Firing Pin

A — A
Cap Rotated for Clarity

A

Shear Pin

Anvil

A
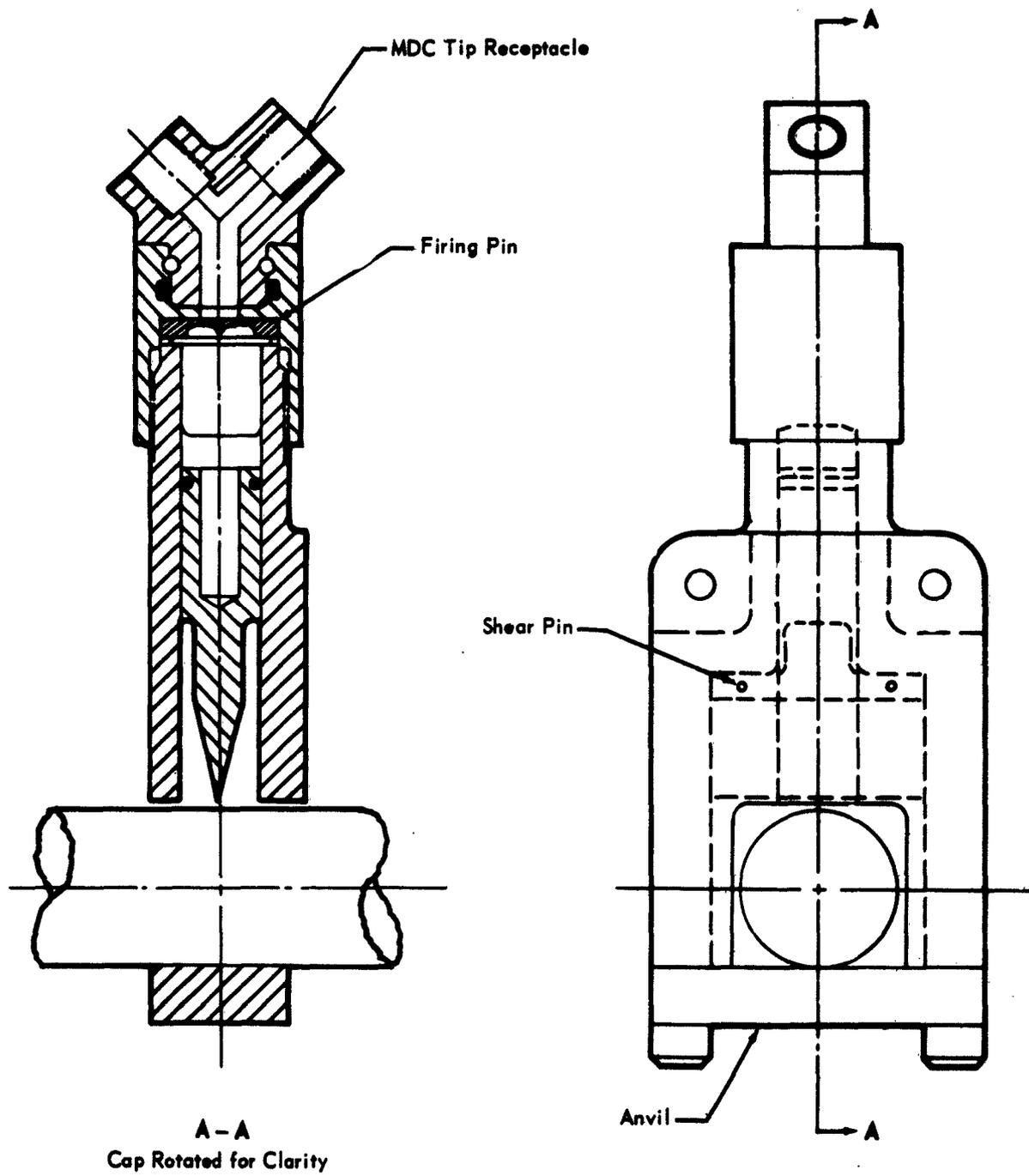
FIGURE 37   CABLE CUTTER

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o   The design of the initiation system shall be such that the output
    from either or both SMDC tips will provide sufficient energy to
    fire the primer in the propellant cartridge.

o   The design of the cable cutter assembly shall be such that when
    initiated by the proper signal the cables will be completely severed,
    and must be free to slide out of the cable cutter after firing.

o   The design of the cartridge for the cable cutter shall be such that
    it may be removed from the cable cutter assembly without the aid of
    special tools.

o   The design of the cable cutter assembly shall be such that it may
    be installed or removed without disconnecting the cables that it
    is designed to sever.

o   The design of the cable cutter assembly shall be such as to provide
    for satisfactory severance when the propellant charge is reduced to
    80% of the specified load, and to operate without component failure
    when the load is increased to 120% of the nominal charge weight.

2.3.1.3 Tubing Cutters and Disconnects

The methods applicable for severance or separation of hydraulic or pneu-
matic lines, are basically similar to those discussed in the preceding
section. The major difference between the devices discussed herein and
those previously covered is the frequent necessity for sealing the lines
after cutting.

In the case of a guillotine, a more sophisticated design must be incor-
porated, to permit crimping of the lines simultaneously with their
severance. This can be accomplished by the use of a double-acting
guillotine in which two specially contoured flat blades are placed on
either side of the cutting blade. Upon initiation, the crimping blades
first contact and crimp the tube on either side of the point to be cut.
When the crimping force reaches a predetermined value, shear pins fail,
releasing the crimping blades from the cutting blade and thus allowing
the cutter blade to continue its stroke and sever the tube. To enhance
the sealing of the tube ends, it is desirable to have the tubing coated
internally, in the area to be sealed, with a plastic material such as
teflon. The systems described above have been successfully tested and
are being built for use in the Gemini program.

The advantages of this method of severance are similar to those discussed
for cable cutters. The principle disadvantage will be the degree of
effective sealing obtained by this method, particularly if the sealed
ends are subject to high vacuums.

Another technique that can be used is a propellant actuated disconnect
similar to that discussed in the preceding section. In this case,

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however, mechanical check valves are built into the disconnect housing so that upon separation the valves close off the line on either or both sides as required. The advantage of this technique is similar to that for electrical disconnects, with the addition that highly effective seals are attainable, but as with the electrical type they are relatively bulky, particularly if more than one hydraulic or pneumatic lines are involved.

An additional technique for severance and sealing would be the use of FLSC for cutting the lines (also discussed in the previous section) and the incorporation of an explosive valve ahead of the area to be cut, or if necessary on either side of the area to be cut. The same signal used to initiate the FLSC would also be used to initiate the explosive valve or valves. The advantage of this method is its relative simplicity; also, the valve may be placed some distance from the FLSC if required. The disadvantages to the method are the weight and space requirements should more than one line have to be cut and sealed. The accompanying blast effects from the FLSC is a further adverse effect.

Therefore it is recommended that where single isolated tubes are to be cut and sealed, the propellant actuated disconnect be used. Where more than one line is involved then the modified guillotine approach is the more desirable technique to be used (Figure 38).

(a) Design Criteria - Tubing Cutter and Sealer

The following operational requirements are considered to be optimum design criteria for the tubing cutter and sealer (modified guillotine type) to be used in the separation and severance system.

o   The propellant cartridge for actuating the cutter and crimping blade shall be designed for ignition by means of a precussion primer.

o   The design of the housing above the propellant charge shall be such as to provide two threaded ports to accept two SMDC tips with cross-over capability.

o   The design of the initiation system shall be such that the output from either or both the SMDC tips will provide sufficient energy to fire the primer in the propellant cartridge.

o   The design of the tubing cutter and sealer shall be such that when initiated by the proper signal the tubes will be completely sealed and severed, and must be free to slide out of the cutter after firing.

o   The design of the cartridge for the tubing cutter shall be such that it may be removed from the tubing cutter assembly without the aid of special tools.

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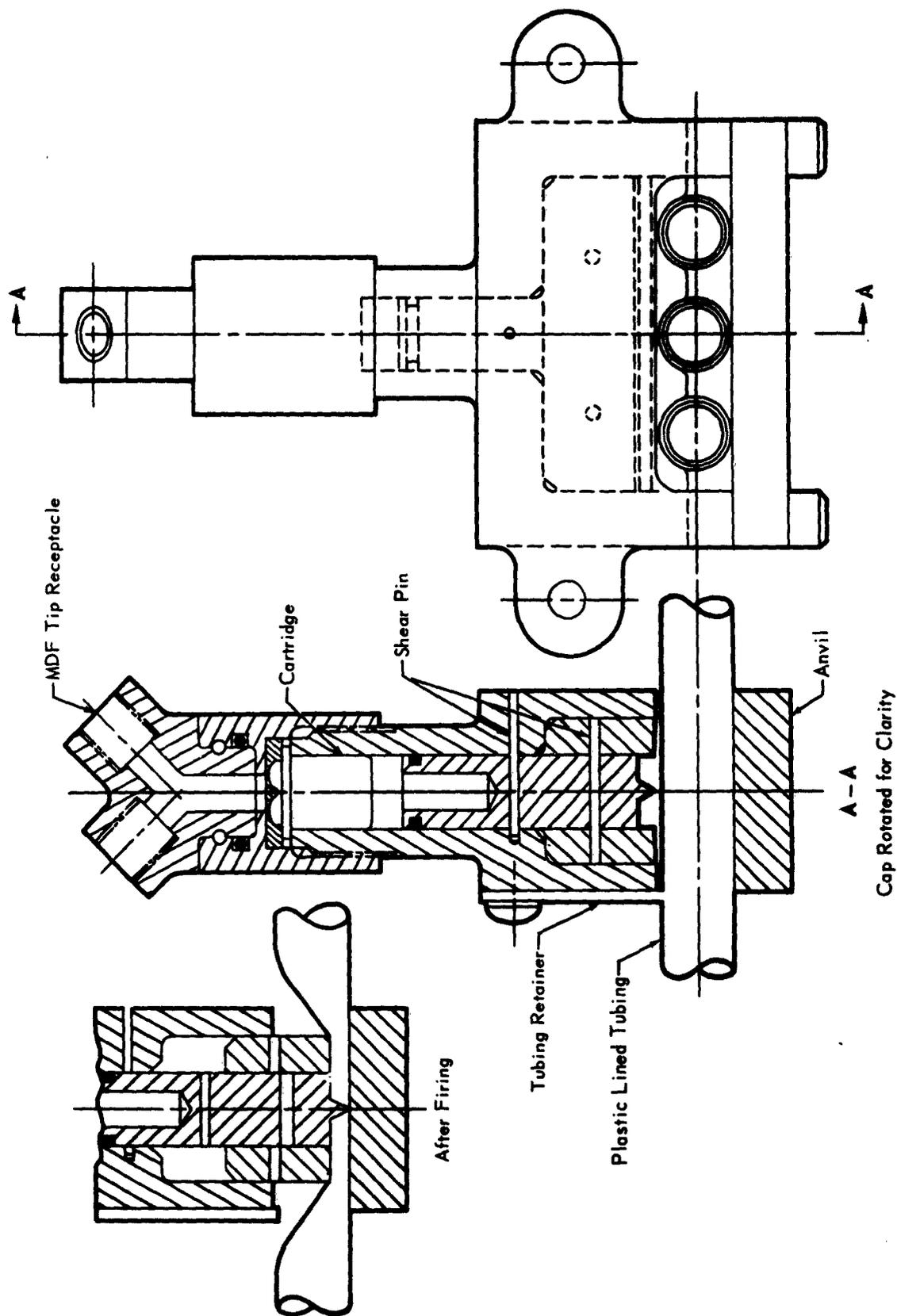
FIGURE 38   TUBING CUTTER AND SEALER

Labels in figure: MDF Tip Receptacle, Cartridge, Shear Pin, Anvil, Tubing Retainer, Plastic Lined Tubing, After Firing, A—A, Cap Rotated for Clarity

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o   The design of the tubing cutter assembly shall be such that it may
     be installed and removed without disconnecting the tubes that it
     designed to sever.

o   The design of the tubing cutter and sealer shall be such as to pro-
     vide for satisfactory separation and sealing if the wall thickness
     of the tubing as specified is increased by a factor of ten per cent.

(b) Design Criteria - Propellant Actuated Fluid Disconnect

The following operational requirements are considered to be optimum design
criteria for pyrotechnically actuated disconnects to be used in the separa-
tion and severance subsystem:

o   The power cartridges for actuating the disconnect shall be designed
     for initiation by either of two standard SMDC booster tips.

o   The firing head shall be so designed that it accepts two SMDC end
     fittings, and that either tip will cross-initiate the other tip,
     as well as actuating the power cartridge of the disconnect.

o   The firing head shall provide an environmental seal for all com-
     ponents before and after actuation.

o   The design of the propellant actuated disconnect shall be such that
     when initiated, it will separate satisfactorily, and each half of
     the separated unit shall be sealed such that the leakage rate past
     the seals shall not endanger or impair the operation of the escape
     capsule. Fluid seals shall be compatible with the fluid associated
     with the disconnect.

o   The design shall be such that all components, including the power
     cartridge, can be removed without the use of special tools.

(c) Operation of the Propellant Actuated Fluid Disconnect (Figure 39)

Initiation of the pressure cartridge causes the expanding gases to enter
the annular chamber between the male and female body sections. This gas
pressure acts against both these body sections, causing the shear pin to
fail and the left-hand (male) section to be ejected from the mounted
right-hand section or housing. As this movement continues, the contact
between the poppets is eliminated, and both poppets are free to move
toward each other, and hence their respective seats. They are urged
toward this closed, or sealed, position by the compressed springs behind
them, as well as by the fluid pressure behind them.

It should be noted that it is desirable to use a flexible fluid line on
the left-hand or movable end of this disconnect. While it would work
with rigid lines on both sides, as the capsule moved away from the command
module, the lines would leak during the time required for the necessary

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Shear Pin

Mounting Lug

Poppet

Cartridge

MDF Tip Receptacle
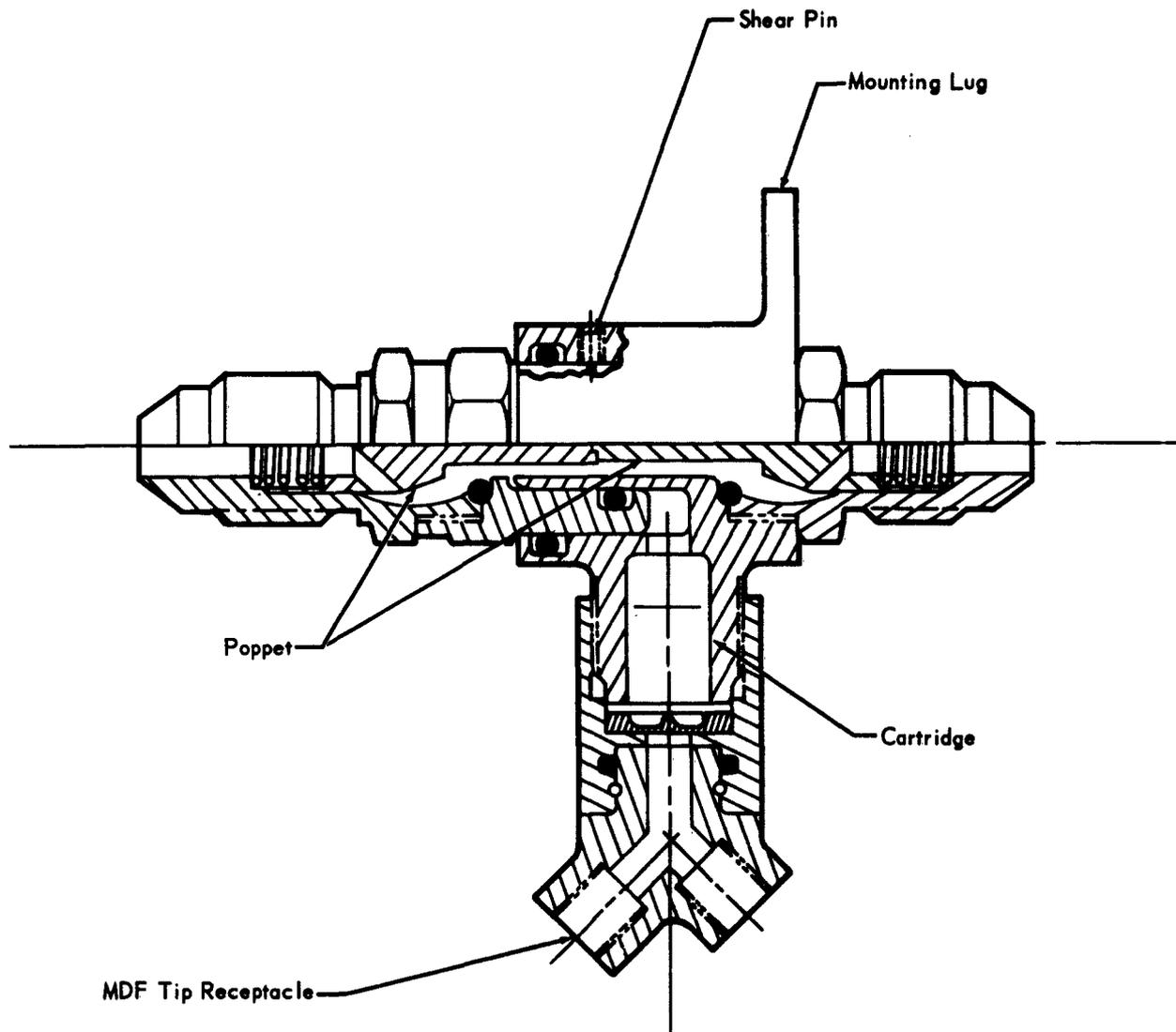
FIGURE 39   PROPELLANT ACTUATED FLUID DISCONNECT

motion to be achieved. This could create a potential hazard, depending on the fluids carried through the disconnect.

2.3.1.4 Separation Devices

Separation of the Crew Escape Module can be achieved through the use of any number of different techniques. Some of the more common methods include the use of FLSC, MDC, Shear bolts, separation nuts, and explosive bolts. The use of FLSC as a separation technique has found wide acceptance because of its relative advantages of low weight, high reliability, and adaptability to large separation planes. Since FLSC achieves separation through actual severance, the application of the technique to a given vehicle will quite often involve the use of an adapter section. However, in the case of modular-type construction, where interconnecting ties are made through concentrated load paths, FLSC becomes less attractive from the standpoint of the large amount of explosive required to sever heavy and irregular sections. The desirability of utilizing FLSC in such instances is reduced still further when it becomes necessary to completely contain the back blast energy.

The application of MDC to separation system design has been limited primarily to relatively thin-skin cutting, or for hatch cover removal. One method for accomplishing the latter utilizes the MDC blast energy for bolt breaking purposes, thereby achieving separation. Since in most designs the bolts undergo a tension failure, the MDC must deliver enough energy to bring about physical separation and actual movement of the connected structures. If the structures so connected are both heavy, the forces required to provide this movement, and hence the structural strength necessary to withstand them, may be prohibitive. Attempts to design around this basic problem area, by such means as breaking out the structure around the bolt heads, will quite often lead one to conclude that FLSC could be used just as, if not more, advantageously than MDC.

A shear bolt, another method by which to achieve separation, generally consists of a two-part bolt held together by a shear pin. Application of either propellant or explosive energy will induce displacement in one or both ends of the bolt, preceded by shear pin failure and followed by structure separation. There are an obvious number of advantages such as no fragmentation, no deformation, and design flexibility associated with shear bolts. On the other hand, however, the obvious realization is that the shear pin is the prime load-carrying member and successful operation depends on the ejection of a minimum of one part. Another undersirable facet of shear bolts has to do with the binding loads that can be induced if the separation plane is subjected to a sudden, high-shear load at the time of initiation. The basic problem of achieving simultaneity must also be closely scrutinized through consideration of the inevitable difference in shear-pin properties.

One of the more attractive means of achieving separation is through the use of separation nuts. Such devices are generally operated by a power

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cartridge which upon initiation induces displacement of a retainer housing and brings about an out-and-away camming action of a segmented nut from a standard structural bolt. Considering for a moment the application of separation nuts to the crew module escape system with which this study is concerned, immediate attention is drawn to abort modes G and H. In these two modes theoretically simultaneous operation exists between the posigrade, retrograde, and landing abort rockets. From a more realistic point of view, however, it is highly conceivable that the landing abort rockets could reach operating pressure some measurable time before the retrograde motors. Such a situation would undoubtedly product shear loads in the bolts to which the separation nuts would be attached. As touched on in the discussion of shear bolts, only partial ejection of the bolt would not allow complete and simultaneous separation, and could introduce a violent and perhaps destructive pitch-up in the crew escape module.

Of all the methods considered to achieve reliable separation, explosive bolts are recommended for the vehicle under study. This selection has primarily been made as a function of the vehicle's structural make-up with emphasis placed on operational simultaneity and proper performance in every mode of abort. A typical bolt installation is shown in Figure 40.

(a) Design Criteria - Explosive Bolt

In addition to the environmental design criteria outlined in the Appendix, the explosive bolts should fulfill the operational design requirements outlined below. It should be noted that the listed requirements are by no means considered all-inclusive, but generally are intended to reflect some of the more pertinent design considerations.

o   The bolt must be capable of withstanding, with a margin of safety, any load or combination thereof that would result from any mission the vehicle is assigned.

o   The bolt must be capable of complete separation under any set of loads with any combination of the environmental requirements outlined in the Appendix.

o   The bolt must be capable of complete separation when subjected to a no-load condition, including the elimination of preload, and confined in a manner duplicating those conditions which exist in the vehicle.

o   The design of the bolt shall be such that upon detonation of the explosive charge a minimum number of fragments shall be emitted. Every effort should be made in the design of the bolt to reduce the number and size of fragments to zero.

o   The explosive bolt design shall be such that the least possible impulse is imparted to the structure of the crew escape module during separation.

Receptacle for MDC Tip

Explosive Bolt

Mold Line

Separation Surface

Escape Module

Equipment Module
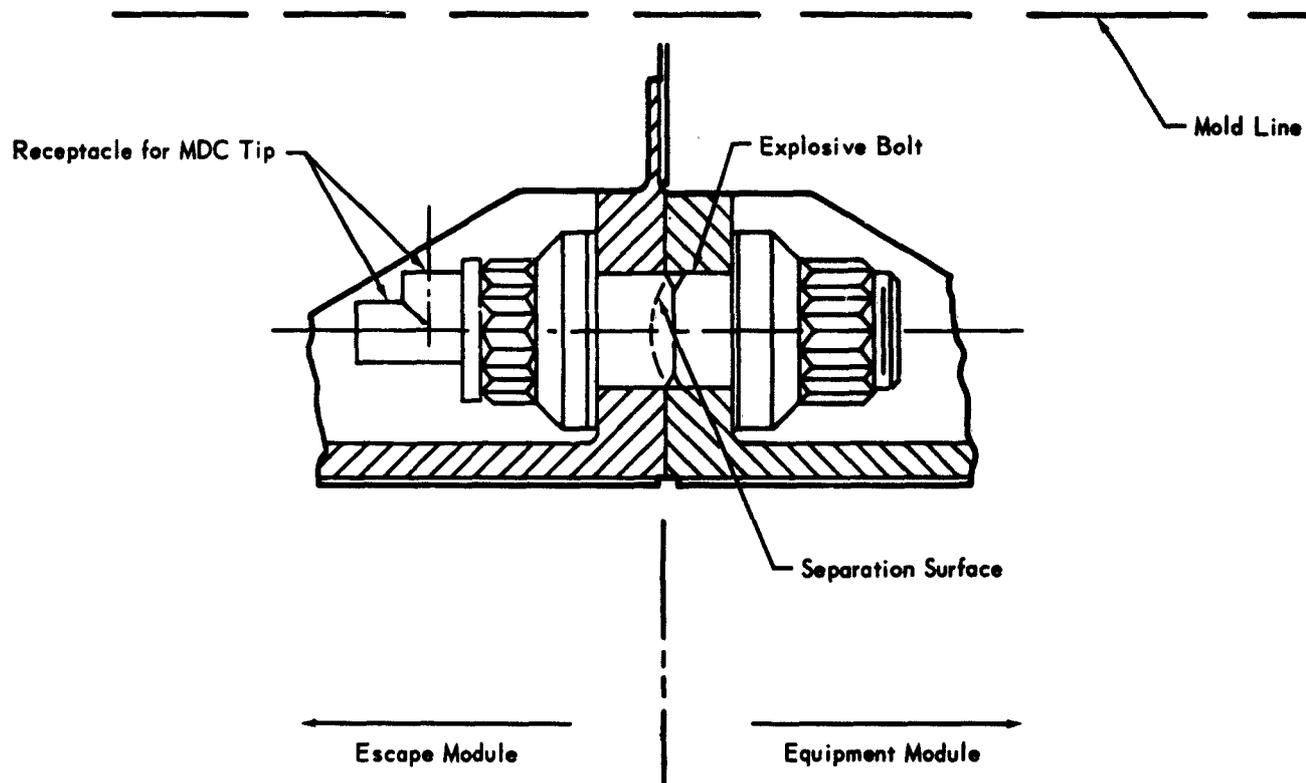
FIGURE 40   EXPLOSIVE BOLT INSTALLATION

o   The bolt design shall be such that all explosive materials are herme-
    tically contained in a one-piece removable cartridge. Both the cart-
    ridge and bolt design should be such as to facilitate installation of
    the cartridge at some convenient time prior to launch without the use
    of special tools.

o   The explosive bolt design shall be sealed against all natural and in-
    duced environments. The seals should have a life equivalent to, and
    preferably in excess of, the explosive cartridge.

o   In order to facilitate installation, the explosive bolt design shall
    incorporate an SMDC tip receptacle capable of rotating 360
    degrees at the time of installation.

(b) Preliminary Bolt Design

Shown in Figure 41 is the preliminary design for an explosive bolt which
utilizes the ridge-cut, or reinforced shock wave principle of operation,
and is capable of fulfilling the design criteria outlined in the preceding
section. An MDC-type tip has been utilized for stimulus transfer and main
charge initiation. In order to overcome the problem of fragmentation, the
bolt has been designed to break in tension and thus gives rise to no flying
fragments except the endwise thrust of the two halves. The method used to
design the bolt, commonly referred to as the ridge-cut technique, will
greatly reduce the amount of explosive needed to fracture the bolt and thus
minimize the end thrust.

Another type of design, which uses low explosives or propellants, and which
is generally called a "pressure bolt," was not considered here because it
results in much higher component velocity and higher back blast energy.

The ridge-cut technique, which utilizes high explosive shock energy, has
been thoroughly covered in literature on fracturing of metals, and need
not be dwelled upon in this report. However, there is one basic difference
between the ridge-cut applications most frequently described and the explo-
sive bolt.

In most applications of the ridge-cut technique, a planar shockfront is
used, and the shock wave produced by the explosive travels in a plane
perpendicular to the surface of the metal. Therefore, the reflected
shock waves (rarefaction waves) return from the opposite face of the
target metal in a direction perpendicular to that face, while the rare-
faction waves are reflected from the surfaces of the ridge at an angle of
(180°-incident angle). Thus the fracture plane, which occurs at the locus
of intersections of the rarefaction waves, is easily predicted.

In the explosive bolt, however, the explosive load is located along the
axes of the bolt, and is detonated from one end. In such a geometry the

Labels on figure:
- Plastic
- MDC
- Separation Plane
- Explosive
- Ferrule
- Crimp Seal
- Stitch Weld
- MDC Tip Receptacle
- MDC Tip
- Alternate MDC Tip Receptacle
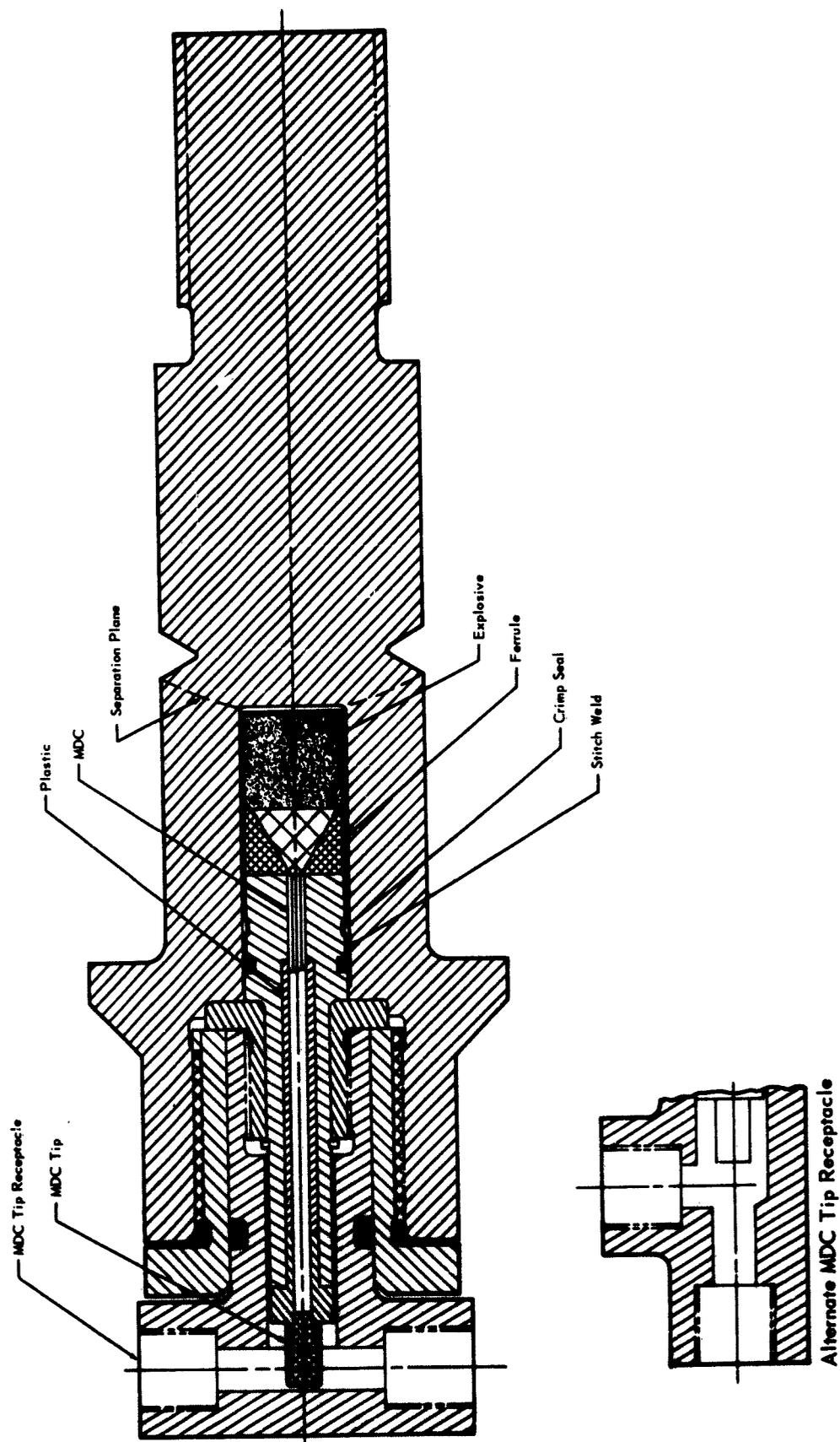
FIGURE 41 EXPLOSIVE BOLT

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shock waves no longer move in a direction normal to the exterior surface of the metal; rather, they intersect these surfaces in a "sweeping" action. Consequently, care must be taken in the design of the ridge in order to obtain the desired cut.

If one wishes to determine the position of the ridge cut and the location of other potential fractures, it is possible to make a simple graphical analysis in the following manner.

o   Assume that shock velocity and rarefraction velocity are equal and constant.

o   Assume detonation is in the form of a plane front moving through the charge from the point of initiation.

o   Assume no rarefractions eminate from the charge space.

o   Select the explosive to be used and determine its detonation velocity.

o   Select the metal to be used and assume a representative shock velocity.

Taking zero time to be the instant of initiation, one can construct the position of the detonation front, shock front, and rarefraction front at various time intervals after initiation. At the time the shock front reaches a metal surface, a rarefraction front starts back into the metal with the same velocity with which the shock front moved outward. When two rarefraction fronts meet along a line, such as AB in Figure 42, a potential fracture surface is produced. The fracture will propogate as the rarefractions move back into the metal and at the moment the fracture reaches the internal void where the explosive is located, the bolt will part.

Figure 43 shows the results of the very first test of an explosive bolt designed with the ridge-cut technique. Although further development tests would undoubtedly be required, it is believed the depicted unit vividly points out the usefulness of the ridge-cut technique in the design of explosive bolts. The belling of the particular bolt shown is due to the bolt's being fired completely unconfined.

Unshocked Material

Shocked Material

Material Behind Relief Front

Explosive Charge
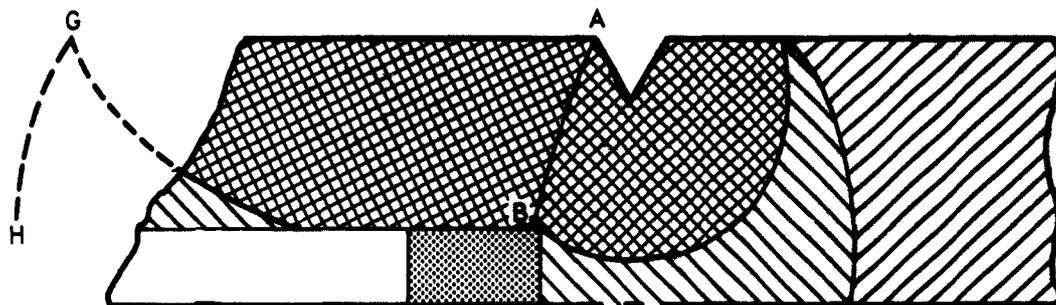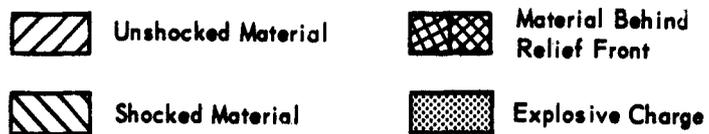
Bolt Section – Annular Grooved 120° Ridge
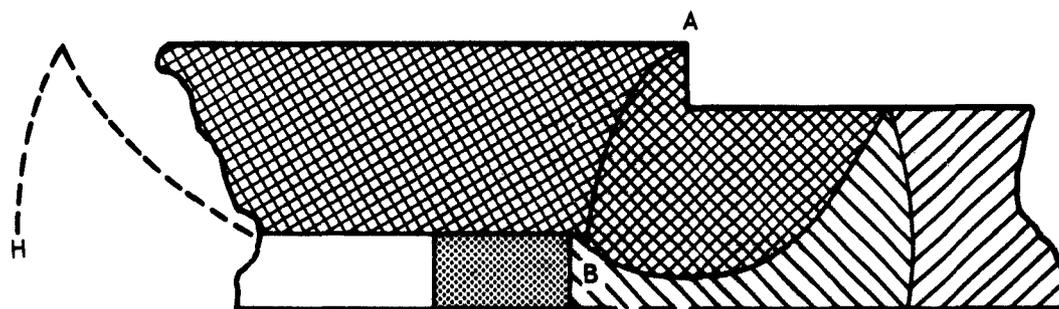
Bolt Section – Integral 90° Ridge

FIGURE 42   EXPLOSIVE BOLT SHOCK PATTERN

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FIGURE 43 EXPLOSIVE BOLT AFTER FIRING

2.3.2 Tower Subsystem

Should an abort signal be received during either the Mode A or B
portion of the flight trajectory, the tower subsystem will be initiated
simultaneously with the separation subsystem. In such a case, simul-
taneous initiation will exist between the tower escape rocket and two
redundant, one-second, time-delay switches. Since the tower escape
rocket has a theoretical burning time of one second, the time delay
switches will conceivably close at some time during motor tail off.
Upon closing of the switches, two initiators will be fired which will
simultaneously operate the three PAD that disconnect the tower and
ignite the tower separation rocket. At the same time, two redundant
short-time delay cartridges will be initiated to operate an electrical
disconnect. The purpose of time delay in the electrical disconnect
cartridge is to allow the same electrical stimulus to initiate the
tower jettison motor.

Shown in Figure 44 is the schematic for the tower subsystem. An
examination of the schematic will show that complete redundancy
exists for initiation of the escape and tower jettison motors, elec-
trical disconnect cartridges, time delay switches, tower disconnects
and their respective initiators. In addition, each electrical initiator
would contain dual, independent bridgewires.

The tower subsystem's initiation stimulus is both electric and MDC in
nature. In order to insure simultaneity of operation, MDC has been used
to initiate the tower disconnects. All remaining units are electrically
initiated. The basic reason for selection of the electrical technique
is the problem of transmitting the initiating stimulus, whether electri-
cal or MDC, through the vehicle's skin. This problem was compounded by
the need to maintain a "clean" aerodynamic surface capable of withstand-
ing the high skin temperature associated with radiation cooled vehicles.
Based on a preliminary analysis, it was concluded that an optimum design
could best be evolved through the use of a propellant actuated, electrical,
quick disconnect.

2.3.2.1 Tower Motor and Jettison Motor Igniters

The stimulus for firing the initiators of both the tower motor and the
tower jettison motors will be electrical; therefore, the 1-amp, 1-Watt
no-fire requirements discussed in Section 3.3.2 are applicable and will
not be further discussed. The type of initiators normally used for
motor ignition are the pyrotechnic type igniter cartridges, and therefore
a brief discussion of igniter ballistics is desirable.

In an igniter, the sum of the interaction between the various components
of the igniter is its effective output. Further, this interaction deter-
mines the rate and manner in which the energy for ignition is delivered.
In order to determine the optimum ballistic design for a particular
system, the correct balance between the various active components must be
determined, usually by experiment. With the many restrictions levied
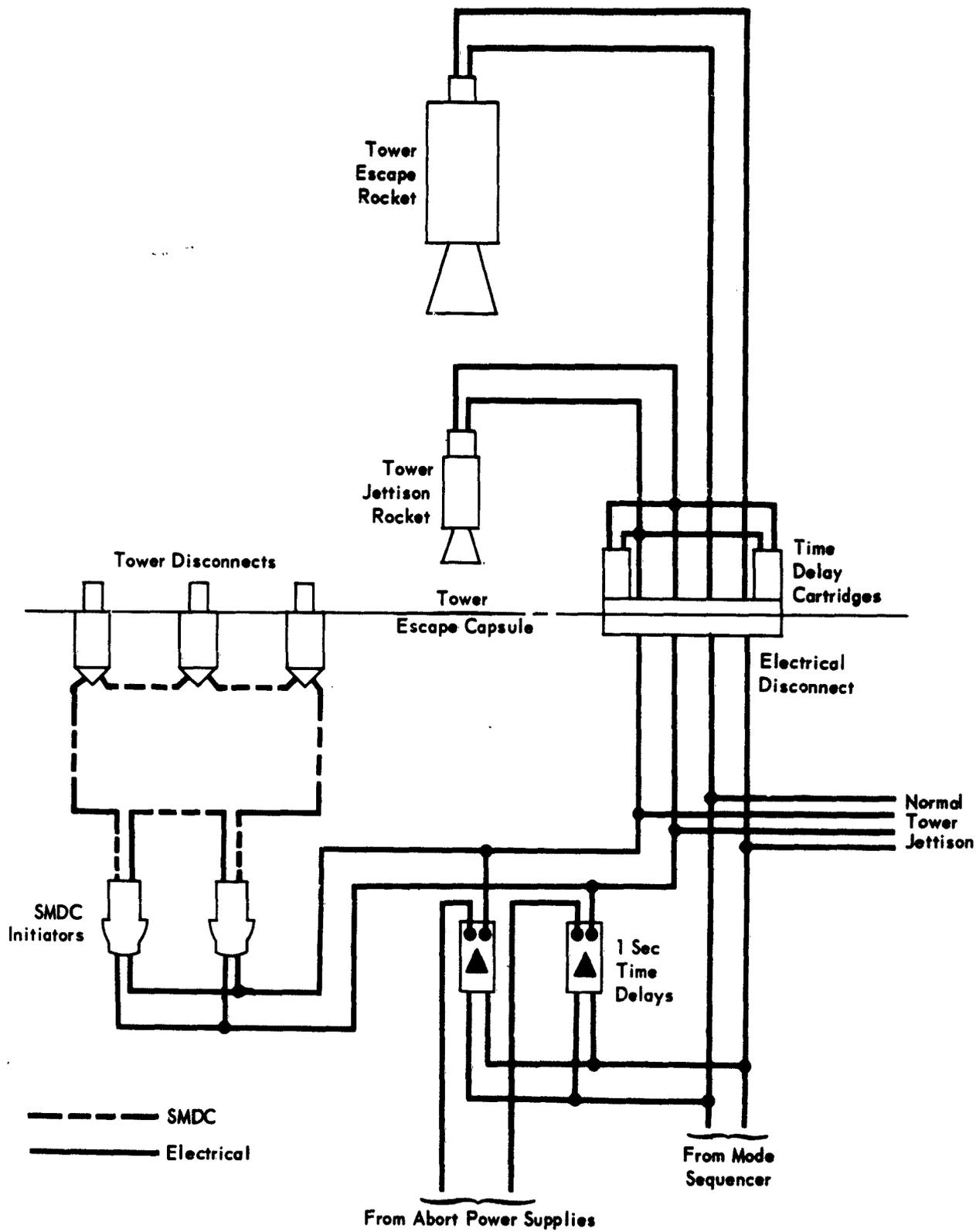
FIGURE 44 TOWER SUBSYSTEM

against the igniter designer various techniques must be used to control the ignition system. These include such things as the choice of slow or fast burning propellants or pyrotechnics, powder or pelleted materials, the selection of the proper composition or combination of compositions to provide the gas and heat required, and the selection of the composition and configuration to give required burning time and maintain chamber pressure at the required value until combustion equilibrium is reached.

(a) Igniter Materials

The principal characteristics of igniter materials are their relative ease of ignition and their highly exothermic self-sustaining reaction. More than one igniter material may be involved in the ignition "train." Depending upon their function within this train, they may be called booster, main or sustainer charges. Furthermore, classification by geometrical configuration, such as granules, pellets, grains and powders, has also been used with ignition materials. From the standpoint of chemical composition they can also be classified into three types, namely, formulations of black powder, metal-oxidants, or solid propellants (pyrogens).

To briefly summarize the properties of black powder, it is a mixture of potassium nitrate, charcoal and sulfur. Upon ignition it produces quite large amounts of gases together with a considerable amount of incandescent solid particles. The heat of combustion is 720 cal/gram and the flame temperature is in the region of $3880^{\circ}F$ ($2138^{\circ}C$). The principal disadvantages to the use of black powder are its hygroscopicity, low calorific output, high ratio of gas to solids in combustion products and the tendency of black powder to quench when ignited at low pressure conditions. Also, the control of particle size is very limited, leading to poor ballistic predictability.

Metal/oxidant compositions, on the other hand, generally have high heats of reaction, high flame temperatures, and are high in the emission of incandescent solid particles. They not only achieve ignition by radiation and convection of heat to the propellants surface as with black powder, but ignition also is assisted by the impingement of the hot metal particles and to some extent condensation of metal vapors on the propellant surfaces. A wide variety of metal-oxidant compositions have been successfully used for a number of years, and will be discussed briefly. These include boron/potassium nitrate, boron/barium chromate, aluminum/potassium perchlorate, and teflon/magnesium formulations.

Boron/potassium nitrate formulations normally are used in the form of pellets or granules. They have a considerably higher heat of reaction (both by weight and by volume) than black powder, in the order of 1500 cal/gram. Further, they have a lower hygroscopicity and a much higher autoignition temperature ($700^{\circ}F$) than black powder.

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Boron/barium chromate formulations normally are used in powder form. They have fairly low heat of combustion (300 to 400 cal/gram) but possess the unique property of being readily ignitable and self-sustaining at low pressure environments. Their autoignition temperature is high (above 1000°F).

Aluminum/potassium perchlorate formulations normally are used in pellet form. They have a high heat of combustion (2400 cal/gram) but are fairly difficult to ignite. Because of a high burning rate exponent at high pressures, it is important to provide unrestricted gas flow through the igniter material to avoid rupture or detonation in the igniter. The autoignition temperature for these formulations is approximately 1000°F.

Magnesium/teflon formulations are used in both the powdered and pelletized form. The heat of combustion is in the neighborhood of 1600 cal/gram, with an autoignition temperature of approximately 900°F. It is difficult to ignite but is excellent for low-pressure ignition purposes.

In the use of solid propellants as igniter materials, it has become customary practice to incorporate the propellant in a miniature rocket motor. This type of ignition system generically has been called a "pyrogen." With the use of higher energy propellants enclosed in pressure vessels with a relatively low safety factor, the need for a reliable and reproducible ignition system, capable of discharging controlled quantities of energy, was fulfilled with the use of the pyrogen approach. Basically it is an ignition system wherein the combustion of the igniter materials takes place in a chamber and the products of combustion (gas and solid particles) are vented into the main rocket motor chamber. As a result, the igniter designer simply has to utilize the rocket motor theory for the design of the ignition system. This places the design on a more scientific basis rather than on an empirical basis.

(b) Design Criteria - Tower Motor Igniters

In addition to the environmental requirements which are outlined in the Appendix, the tower motor and jettison motor igniters must fulfill certain operational requirements. The requirements, pertaining to no-fire characteristics, have already been discussed in detail in the section 3.3.2 on electric initiators.

Other than the above criteria, the initiators must be capable of producing sufficient pressure and thermal energy to bring about sustained combustion of the ignition charge of the overall ignition system in which it is used.

With the overall ignition system, which includes the initiators, ignition charge and pyrogen, it is preferable to locate this at the front end rather than the nozzle end of the rocket motor. This is because the hot ignition gases must pass the full length of the rocket motor grains before reaching the nozzle, and as a result, gives more reliable ignition at low temperatures, and generally shorter delay times at any given temperature.

(c) Design of the Pyrogen Igniter

The preliminary design best felt to fulfill the design criteria discussed above is shown in Figure 45. The two electric initiators are screwed into the boss of the pyrogen body. Located directly below the initiator wells is an ignition charge of boron/barium chromate pellets. These are retained in a heavy wire basket with a wire mesh disc above the pellets to minimize unnecessary motion. A thin plastic rupture disc should be installed between wire disc and the pellets to keep out physical moisture when the initiators are not installed and to provide some cushioning to the pellets. Since the pyrogen grain cannot be case bonded in the chosen configuration, it will have to be a cartridge loaded grain. After installation of the grain into the pyrogen body, the body would then be screwed into the initiator receptor or header of the pyrogen.

2.3.2.2 Tower Disconnect

The tower disconnect PAD is one of the few components associated with the escape system that must operate in every glide vehicle mission, as well as for escape. Therefore, it is mandatory that the tower disconnects function with an extremely high degree of reliability.

Since the problems of tower detachment are somewhat similar to those encountered for the crew module separation devices, it would appear worthwhile to give thought to the techniques mentioned in Section 3.1.6. As such, immediate attention is drawn to the possibility of utilizing a ridge cut explosive bolt. There is little doubt that explosive bolts would reliably release the tower. However, regardless of the many advantages offered by the ridge cut technique, it is not possible within the present state-of-the-art to achieve a smooth and continuous surface at the separation plane, as is required to eliminate localized aerodynamic heating. Thus, the use of explosive bolts for tower disconnect devices must be eliminated from consideration.

Although MDC and FLSC could be used to disconnect the tower, a multitude of problems are foreseeable with regard to protecting the thin, and presumably brittle, external skin from the blast energy. Shear bolts and separation nuts, although compatible with the vehicle's structure, do not have the necessary momentum to overcome the inherent shear load imposed on the bolt by the tower. The problem of maintaining a smooth surface also must be dealt with if shear bolts or separation nuts are used.
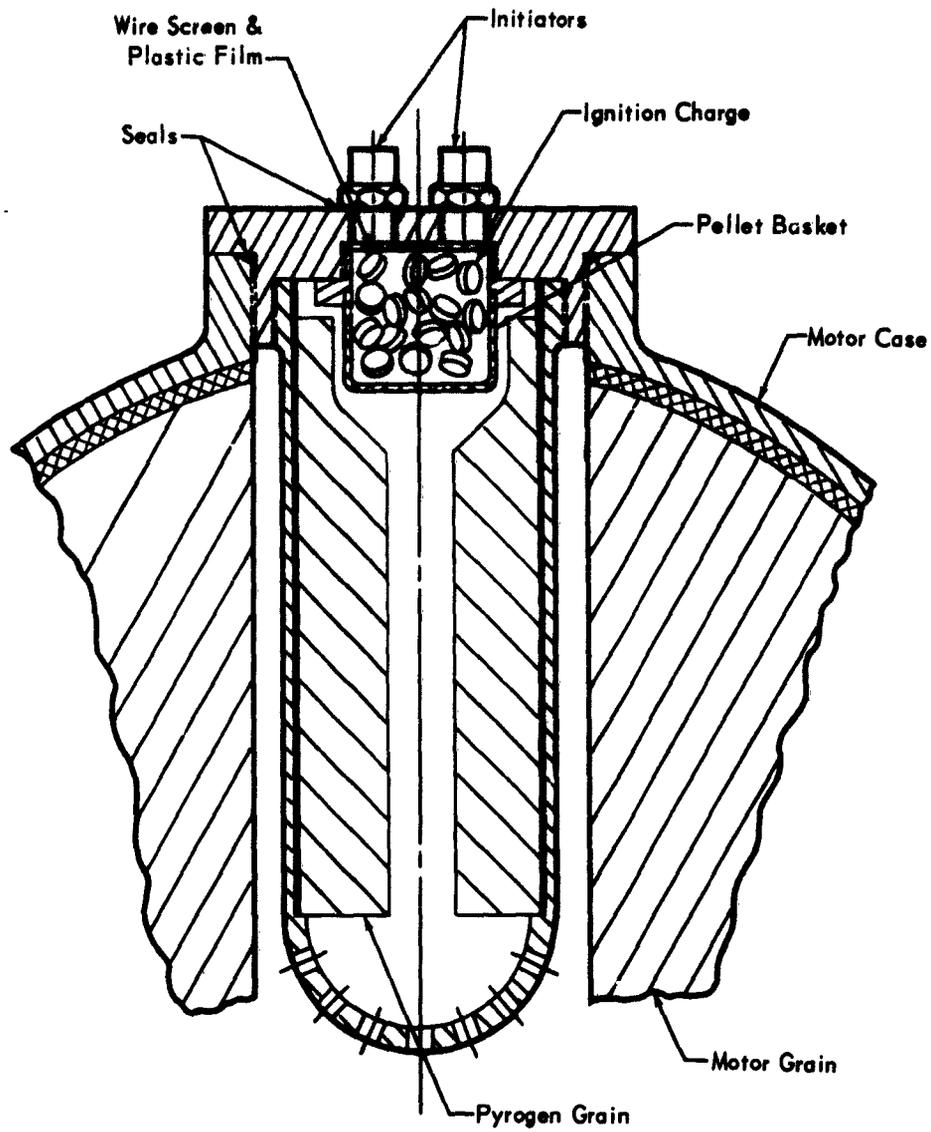
FIGURE 45   ROCKET MOTOR IGNITER PYROGEN DESIGN

One approach not discussed in the section on separation involves the use of simple thruster or retractor-type devices. There is little doubt that designs for either type of device could be evolved to fulfill the tower separation. In order to make a final selection it would be necessary to make a detailed analysis involving trade-off studies of weight and reliability as a function of the design criteria.

(a) Design Criteria - Tower Disconnect

Regardless of the device selected to fulfill the tower release function, each and every one of the requirements outlined below must be fulfilled. The items listed are intended to represent only major design considerations.

o The tower releases must withstand, with a margin of safety, all flight dynamic loads, including those resulting from attitude correction, in combination with the total weight of the tower system.

o The tower releases must resist, without deformation, any combination of loads resulting from the simultaneous operation of the tower escape and tower jettison motors.

o The tower releases must be capable of completely disjoining the tower from the crew escape module when subjected to either an operating, nonoperating, or no-load condition. Fulfillment of this requirement must be maintained for any combination of the environments outlined.

o The release PAD must be capable of completely containing the internal gas pressure developed upon firing under locked shut conditions at any temperature within the limits of the specified operating range.

o The release device, in its actuated position, must maintain a smooth and continuous surface at the tower attach point consistent with the mold line of the crew escape module. There must be no discontinuities in the surface of that portion of the release device used to maintain mold line consistency.

o The release device and its component cartridges shall be sealed against all natural and induced environments. Life expectancy of the seals should be equivalent to or in excess of the power cartridge portion of the unit.

o The cartridge shall consist of a hermetically sealed one-piece container. The design of the cartridge shall be such as to facilitate installation and removal without the use of special tools.

(b) Optional Release Device Designs

As previously mentioned, either a retractor or thruster-type PAD may be used to fulfill the design criteria for the tower release function. Consequently, designs for both a retractor and thruster have been presented.

The retractor design shown in Figure 46 contains two independent and redundant cartridges. Upon initiation the SMDC booster tips will detonate and physically deform the firing pin which will in turn bring about initiation of a percussion primer. Ignition of the cartridge propellant charge is then achieved through the action of the primer in combination with a pyrotechnic ignition powder. The force of the propellant gas will initially break the shear pin and then retract the piston into the actuator body. At the same time a load will be applied to the plunger piston. Upon completion of stroke, the locking pins, as a result of the plunger load, will be cammed into the locking groove and thus maintain the piston in a fixed position. In the locked position, the end of the retractor piston will maintain a smooth and continuous surface consistent with the mold line of the vehicle.

Figure 47 depicts a thruster-type PAD which would serve to release the tower. Upon receipt of an SMDC stimulus, the cartridge shall ignite and bring about displacement of the piston. The force from the piston is then physically transmitted to the nut body causing failure of the shear lip. Complete operation is discernible by ejection of the nut and tower retaining bolt. At the end of stroke, the locking rings, which also serve as a gas seal, will snap into the locking groove and thus maintain the piston in a flush position with the mold line of the vehicle.

2.3.2.3 Electrical Disconnect

The electrical disconnect as utilized in the tower system represents the means by which an internally generated electrical stimulus is transferred to bring about initiation of the tower escape and tower jettison rockets. Selection of the electrical mode of stimulus as opposed to SMDC has been discussed previously.

At the time of tower jettison, it becomes necessary to completely disjoin the tower from the crew escape module. As discussed in the preceding section, the tower disconnects, through their operation, will provide the basic structural release. In addition, however, some means must be provided to physically separate the electrical lead wires to the tower and thus eliminate the possibility of an undesirable tether action on the tower. As a function of the stated problem, it was determined that a pyrotechnic actuated quick disconnect represented the optimum approach. As opposed to a cable cutter, the disconnect not only performs the prime function of stimulus transfer but also provides, in one unit, the means by which actual separation is achieved. Little consideration was given to a pure mechanical design because of the weight penalty involved.

MDC Tip Receptacle
(Rotated for Clarity)

Cartridge

Locking Groove

A-A

Ball Detent Assy.

Shear Pin

Plunger

Locking Pin
(Typ.)

B-B

B

B
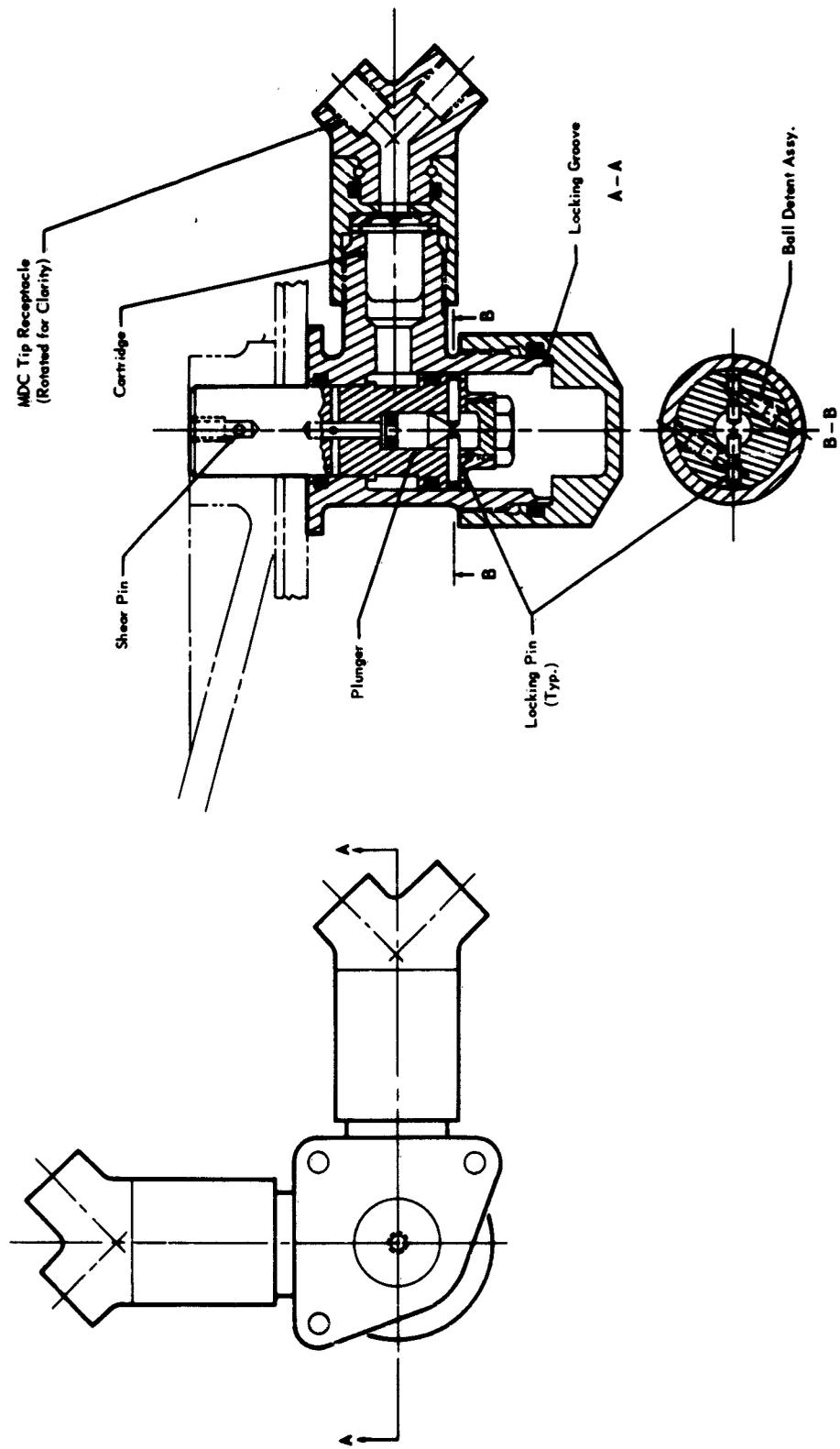
FIGURE 46   TOWER RELEASE-RETRACTOR

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Nut Retainer

Nut

Nut Body

Shear Lip

Piston

Environmental Seal

Gas Seal and
Locking Rings

Locking Groove

End Cap

Cartridge

SMDC Tip Receptacle
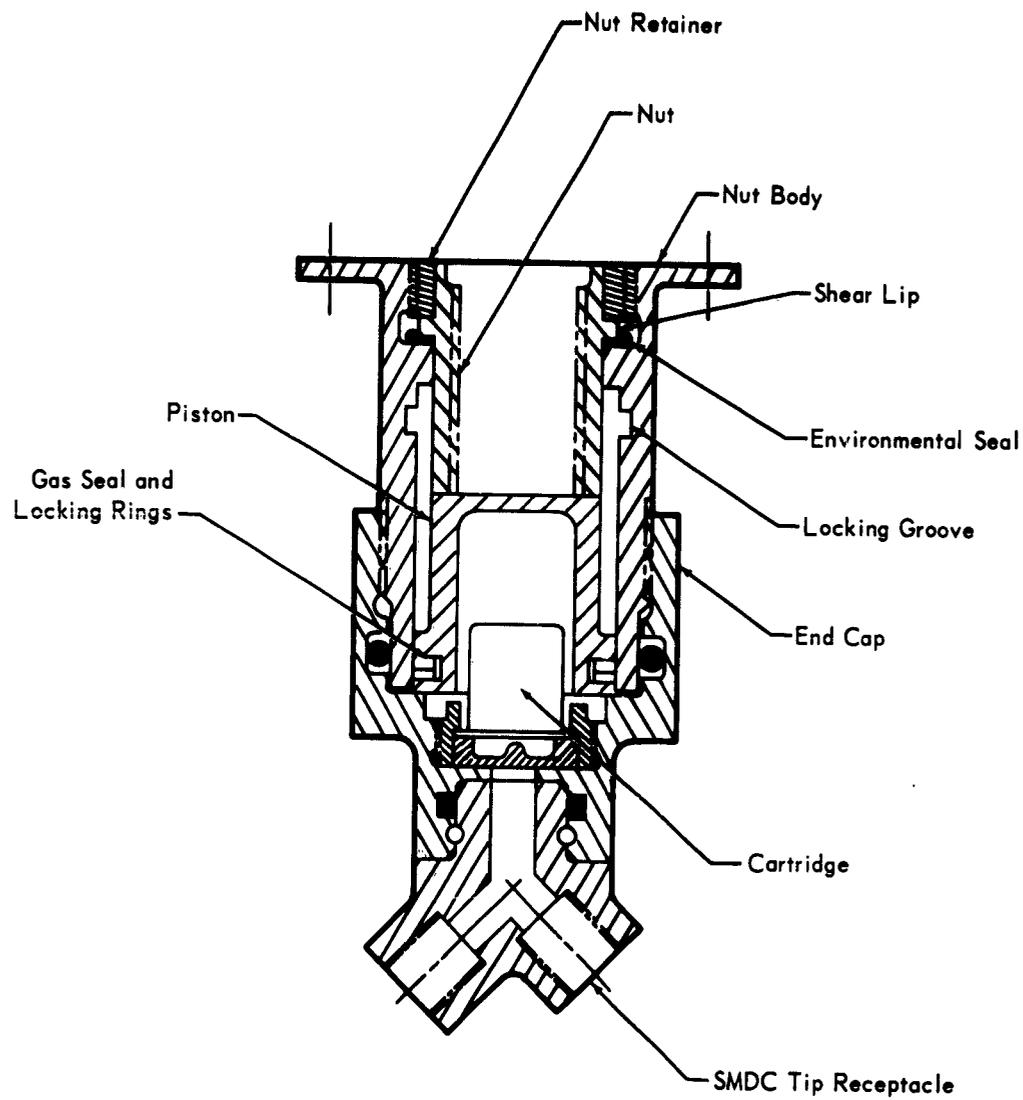
FIGURE 47   TOWER RELEASE – THRUSTER

There are, of course, two basic pyrotechnic methods of providing the energy necessary for separation; explosives and propellants. Of the two, it was determined that the pure explosive approach, such as utilizing MDC to break bolts, could not fulfill the requirement for an aerodynamically clean surface without unduly complicating the design. As such, it was decided that a propellant-powered disconnect represented the best design approach.

(b) **Design Criteria - Electrical Disconnect**

The electrical disconnect, in addition to fulfilling the operating criteria outlined below, also must meet the requirements associated with its basic electrical function. Conformity with both requirements must be made under any combination of the environments outlined in the Appendix.

o   The electrical disconnect shall sustain without separating any load or combination thereof resulting from the flight trajectory of the vehicle up to the time of tower jettison.

o   Complete separation of the electrical disconnect shall be achieved under any combination of natural or induced loads through the action of redundant cartridges at some predetermined time following receipt of the proper electrical stimulus.

o   The design of the electrical disconnect shall be such that following separation a smooth and continuous mold line shall be maintained in the affected area.

o   The operation of the electrical disconnect shall not induce, affect, or otherwise cause any damage to the external surface of the crew escape module. There shall be no significant or potentially dangerous shrapnel emitted as a result of the operation of the electrical disconnect.

o   The design of the electrical disconnect shall be such that final hook-up of the electrical plug and installation of the power cartridges can be performed external to the vehicle without the use of special tools at any time prior, and convenient, to launch.

o   The electrical disconnect and its component cartridges shall be adequately sealed against all natural and induced environments.

o   The cartridges shall be designed in accordance with the general criteria outlined in Section 3.3.2. In addition, the cartridge design shall incorporate a "built in," predetermined time delay compatible with the initiation requirements of the escape and jettison rockets. The design of the cartridge output charge shall be such that either one or both cartridges will fully separate the electrical disconnect.

o   The reliability of the electrical disconnect, including cartridges, shall be compatible with overall requirements of the escape system.

(b) Preliminary Design - Electrical Disconnect

Shown in Figure 48 is a typical design for a propellant actuated
electrical disconnect. Upon receipt of the proper electrical stimulus,
the cartridge delay train shall be ignited. Since it is the purpose
of the time delay to allow for proper ignition of the tower escape and
jettison rocket motor, it is considered reasonable to contemplate a
total delay requirement of not more than 30 milliseconds. Since this
requirement is somewhat unique with respect to normal time delay design
as discussed in other sections of this report, it is considered worth-
while to make brief mention of a few of the methods by which to achieve
short time delays.

Quite often the designer, when confronted with a short time delay require-
ment, will find that the more conventional pyrotechnic mixes do not offer
a fast enough burn rate. As a result the delay train is extremely short
in length, and thus is susceptible to wide dispersion in addition to
being difficult to load. Although some attempts have been made to obtain
reproducible delays by pressing gasless-type ignition powders such as
zirconium/potassium perchlorate, under very high load on to flush bridge-
wire, they have not in general been found to be completely successful.
Digressing for a moment, however, from what might be termed the more
modern gasless delay powders, attention is drawn to the somewhat anti-
quated black powder delay train. Although primarily used in ordnance-
type equipment such as contact initiated projectiles, there is little
reason why black powder with its excellent thermal stability could not be
applied to the delay problem associated with the electrical disconnect.
The prime disadvantage would undoubtedly have to do with the variation
in burning rate that would be encountered from changes in atmospheric
pressure. This problem would be minimized, however, through use of a
hermetically sealed cartridge.

Still, another method of achieving extremely short delays involves the
use of primary explosives such as lead styphnate or lead azide. Although
normally used for extremely short delays, such as five milliseconds, lead
azide has received consideration for times up to 50 milliseconds. More
recently, fuze-type delays have been made which utilize MDC with a lead
azide core.

Regardless of the type of design, termination of the delay train will be
made with an ignition powder which will be used to ignite the cartridge
propellant load. The energy derived from the propellant will force the
piston portion of the electrical disconnect downward. After breaking the
shear pin, and at some point toward the end of the stroke, the reduced
area portion of the piston will pass the ends of the locking tangs. Upon
being free the tangs will spring loose and thus release the upper plug
portion of the connector. At the same time, the piston will be forced
into the tapered friction lock, which also acts as a gas seal. The
friction lock will maintain the piston flush with the mold line of the
vehicle.

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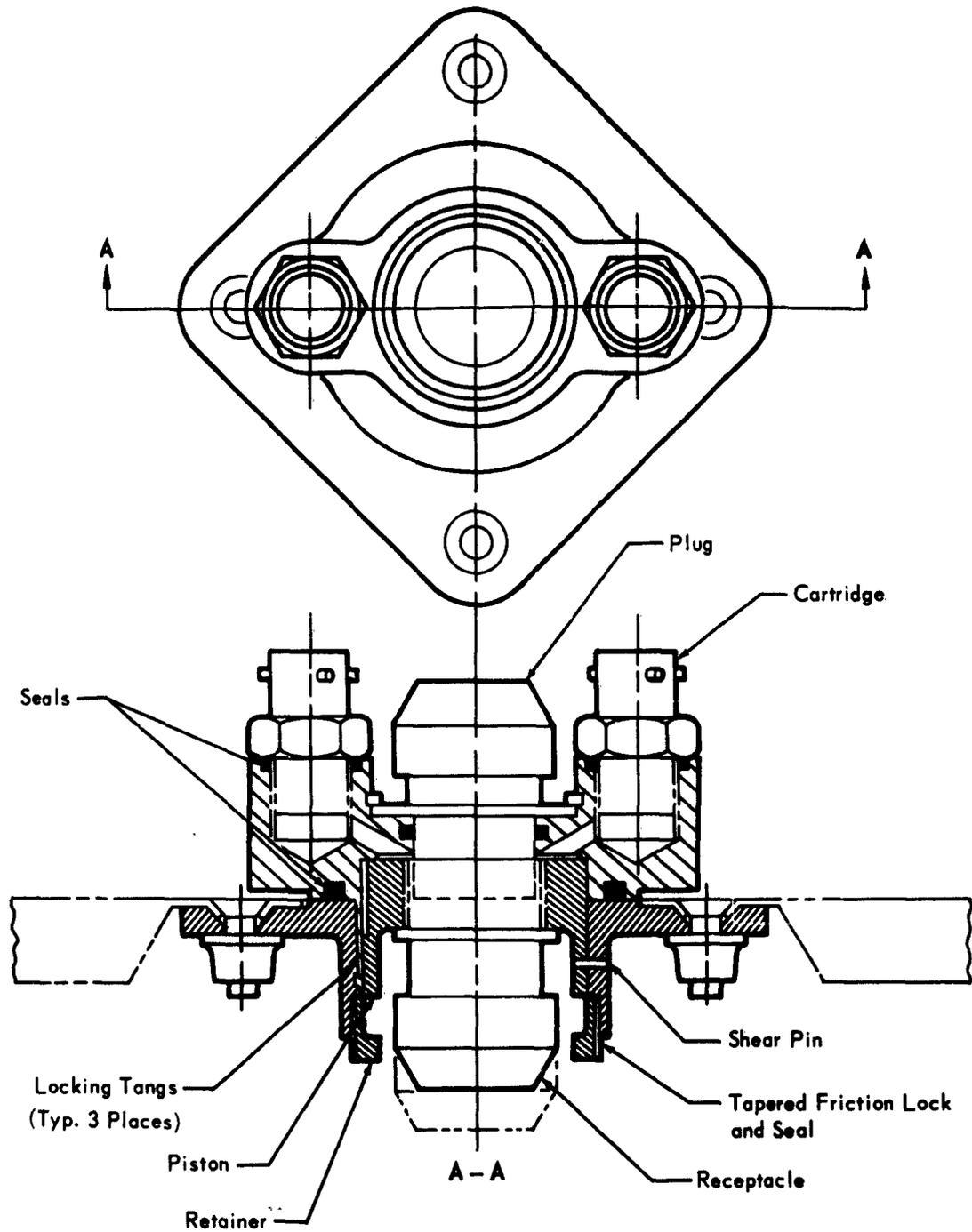
FIGURE 48 PROPELLANT ACTUATED ELECTRICAL DISCONNECT
FULL SIZE

Plug

Cartridge

Seals

Shear Pin

Locking Tangs
(Typ. 3 Places)

Tapered Friction Lock
and Seal

Piston

Receptacle

A – A

Retainer

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2.3.3 Landing Abort Subsystem

2.3.3.1 General

It is the purpose of the landing abort subsystem as depicted in Figure 49 to provide the vertical thrust component required for abort during and after landing. Utilization of the subsystem also is made to provide lateral displacement for launch and early boost abort situation.

SMDC has been selected as the initiation stimulus mode. Like most of the other subsystems discussed in this report, a high degree of simultaneity is required between the operation of the two landing abort rockets and the cover. The choice of one cover as opposed to separate individual covers for each rocket nozzle obviously imposes somewhat of a minor weight penalty. Even more obvious, however, is the fact that the reliability of the landing abort rocket subsystem is considerably improved through the elimination of individual covers and the devices associated with them.

One question that may arise upon reviewing the landing abort rocket subsystem schematic has to do with the initiation of the motors and cover from the same source. The disadvantage of the motors firing prior to cover removal are obvious and thus need not be dwelled on. One possible method of eliminating this problem would be to incorporate delay initiators in the two SMDC lines going to the motors. Careful consideration of such a solution, however, lead to the conclusions that (1) cover removal will be obtained through the use of all high explosives and thus will be released almost instantaneously, (2) There will be an inherent delay in the ignition of the landing abort rockets. Based on the above analysis it was concluded that the ignition delay would adequately allow for complete release of the cover prior to any appreciable pressure build-up in the rocket motors.

Prior to leaving the landing abort rocket subsystem it is interesting to note that the full thrust application of both motors on the crew escape module would impose approximately eleven "g's" on the astronaut. Although this value is within the limits of human tolerance as described in HIAD for an "eyeballs down" condition, it certainly dictates a review of possible astronaut position. As such it is foreseeable that the astronaut could be leaning forward at the time of abort. Should this be the case, it is possible that a back injury could be sustained. In order to alleviate such a condition, the decision was made to equip the escape module with a propellant actuated haul back inertia reel. This device is further discussed in Section 2.3.8.2 of the report.

2.3.3.2 Landing Abort Rocket Igniters

Other than the environmental requirements which are discussed in the Appendix, the landing and abort rocket igniters must fulfill several operational require-ments. These include the ability to function from an SMDC stimulus, the arrangement of which has been previously discussed in association with the initiation of other devices. In addition to this, the initiators must be cap-able of producing sufficient pressure and thermal energy to effectively bring
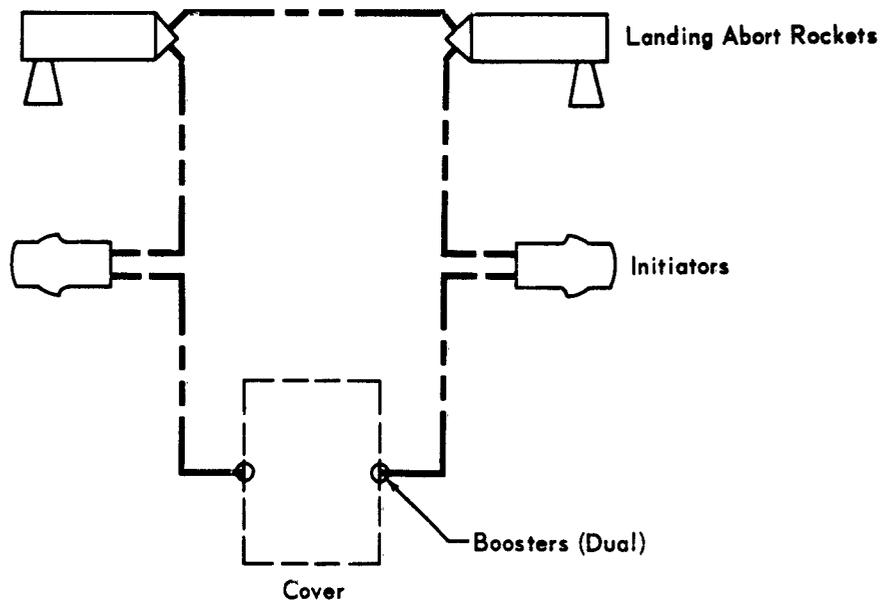
━ ━ ━ ━ SMDC

─ ─ ─ ─ FLSC

FIGURE 49   LANDING ABORT SUBSYSTEM

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about sustained burning of the ignition pellets which form a part of the overall initiator and bring about sustained burning of the motor propellant. As mentioned in the discussion of the tower and jettison motor initiator, it is preferable to locate these initiators at the front or head end of the motor rather than at the nozzle end, in order to have more effecient motor ignition.

(a) Igniter Design

The design selected for the igniters (Figure 50) was chosen for its compactness, an important criteria due to the space limitations imposed. This selected design is known as the pencil or flame tube type arrangement. It essentially consists of an ignition cartridge located below the SMDC receptacles. When either or both SMDC tips function, the firing pin is driven against the primer located in the head of the cartridge. This in turn ignites the pelletized output charge contained in the perforated tube directly behind the cartridge. The spirally wound mylar tape covering the vent holes for moisture protection offers no resistance to this flame front. The multiplicity of flame jets which impinge upon the surrounding propellant surface provides excellent ignition of the latter.

2.3.3.3 Hatch and Compartment Cover Removal

A number of methods have been used for the removal of hatch and compartment covers, four of which are of particular interest.

o   Mechanical unlocking and ejection systems

o   Explosive nuts or bolts

o   MDC "bolt popping"

o   FLSC cutting

Each of the above was discussed briefly in Section 2.1.15, Part I of this report.

Because of the unique geometry of the covers required for the subject vehicle, careful consideration must be given to each of the techniques. The special problems are twofold:

o   The main structure of the cover and its mating "sill" are internal to the capsule, so that overpressure or backblast from explosive charges must be carefully controlled.

o   The cover must be ejected with some force, since aerodynamic forces will not carry it clear of the vehicle.

Considering the second factor above, it is obvious that a simple unlocking device is not sufficient; a form of ejector or remover is required. Furthermore, since the covers are of appreciable size and generally will be
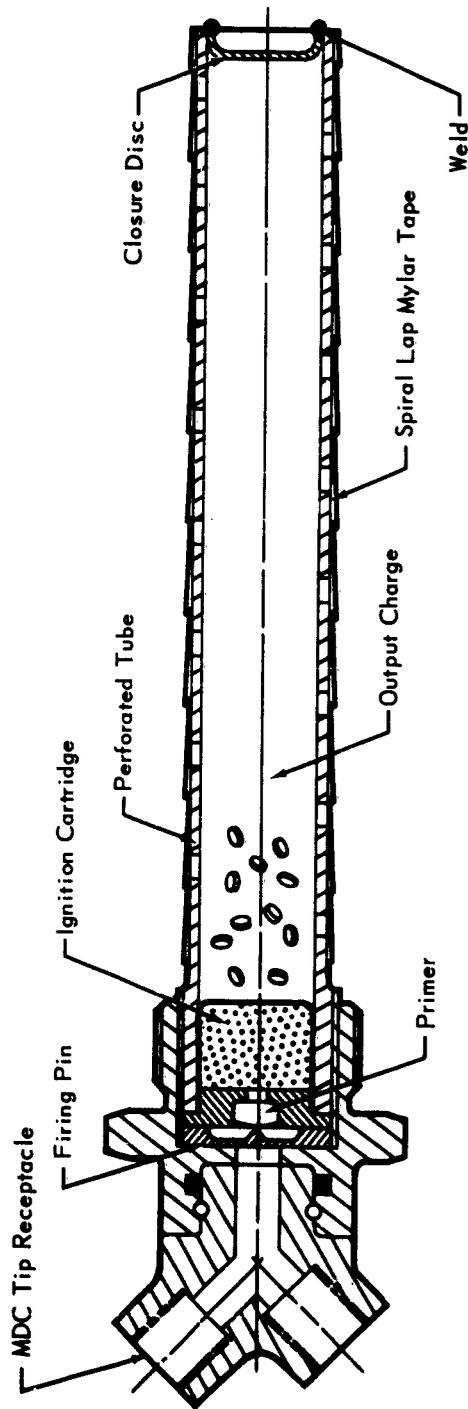
FIGURE 50   PENCIL TUBE IGNITER

Closure Disc

Spiral Lap Mylar Tape

Weld

Perforated Tube

Ignition Cartridge

Output Charge

Firing Pin

MDC Tip Receptacle

Primer

covering a stowage compartment, a single remover, centrally located, is not applicable and a solitary remover mounted on one edge would not reliably throw the cover clear of the opening. Thus, the use of this design approach would require some sort of peripheral unlocking arrangement plus several removers per cover, a formidable weight penalty.

Separation nuts or explosive bolts would involve a similar penalty; a number of devices would be required, involving both a weight and a reliability penalty. Again, a separate remover system would be necessary, since neither separation nuts nor explosive bolts would impart sufficient impulse to the cover to achieve the required separation velocity.

The "bolt popping" technique, utilizing mild detonating cord, is one of the more appropriate methods for this application. The MDC, which is installed around the perimeter of the cover, provides a high rate, high energy impulse which causes the cover attachment bolts to fail in tension, and also imparts considerable momentum to the cover. The velocity bestowed to the cover is a function of its weight. The energy absorbed by the backup structure also is a function of this factor. Thus it can be seen that the method is applicable only to reasonably light-weight covers. For the application at hand, the covers are heavier than usual because they consist of the compartment lid, the external vehicle skin, the intermediate structural members, and the thermal insulation. However, the weight would still fall within the limits for practical use of this method. One of the chief disadvantages of this technique, particularly in the subject application, is the presence of a number of loose bolts after their fracture, some of which might cause the cover to jam into surrounding structure.

From an overall standpoint, it appears that the most desirable means of accomplishing the severance and forceful ejection of the covers is by explosive cutting techniques. Normally, flexible linear shaped charge is used for this purpose. In one typical application of this technique, the velocity imparted to the cover was approximately 50 feet per second.

In severing metal by this method, the mechanism of failure is a combination of two actions: the actual cutting by the charge and the mechanical failure of the metal due to bending and/or tearing. Figure 51 illustrates this action. In aluminum, the required penetration is approximately 40 per cent and the remaining 60 per cent of the metal is severed by mechanical failure.

For any given material, other factors influencing the depth of penetration required to sever a panel include the thickness of the plate being cut, the proximity and rigidity of the supporting structure, and the distance between the supports and the plane of the cut.

The charge required, in grains per foot of FLSC, is controlled by the specific explosive used, the efficiency of the FLSC design (geometry, sheath material), the standoff, and to some extent, the degree of confinement afforded by the housing or backup.

FLSC

Before

Backup or
Supporting
Structure
(Typical)

A

After

Depth of Penetration of Cut

Portion Fractured by
Mechanical Failure
(Bending) of Metal

A
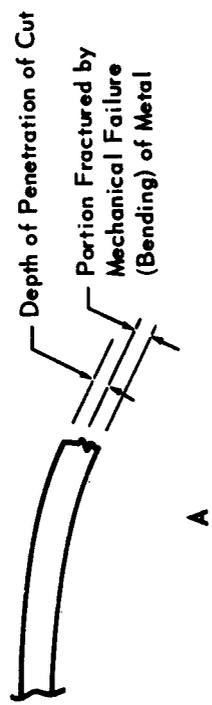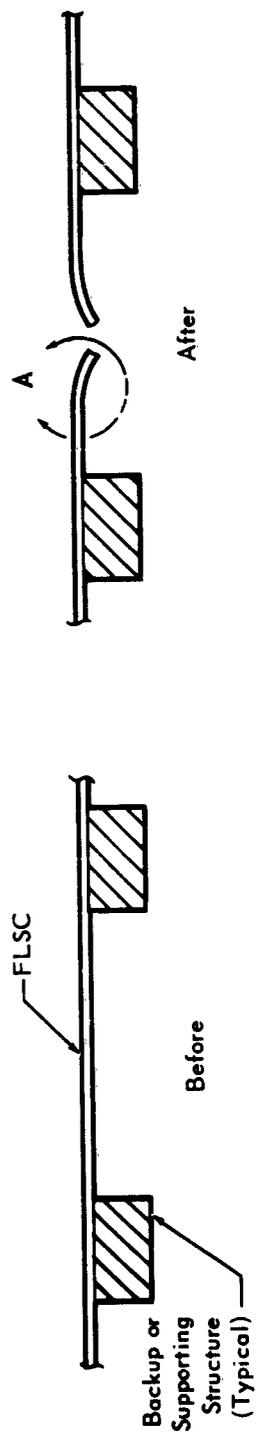
FIGURE 51
SEVERANCE OF A PLATE BY FLSC

From the above, it becomes obvious that no simple graph or equation can be used to determine the design of the system; some development work will be required for each specific cover.

If the plate to be cut is thin, and hence the core loading of the FLSC is less than 10 grains per foot, there is value in considering the use of MDC rather than FLSC. While it is true that the cutting efficiency is lower, the reliability of propogation is much higher in the low core load values. This is true because in low core loads the cross-sectional thickness of the V-shaped explosive charge of the FLSC is small, whereas the diameter of the explosive charge in MDC, for the same loading density, is much larger. Furthermore, the round shape of the MDC, occupying much less cross-sectional area, frequently makes it possible to imbed the charge in the piece to be severed rather than in a separate holder or a thickened and specially contoured section.

Without more detailed information about the structural loads on the compartment covers, the thickness of metal to be cut cannot be ascertained. Thus the precise determination of whether MDC or FLSC is the more desirable explosive element cannot be made. Since any design using FLSC can readily be adapted to the use of MDC, the proposed cover severance system utilizes FLSC. Figure 52 shows the arrangement of components for the FLSC severance of a typical compartment cover on the escape capsule.

Normally, the FLSC would be arranged to cut inwardly; i.e., in a direction from the skin into the interior of the capsule. Contrary to what might normally be expected, this imposes smaller loads, and less of a tendency to damage internal components and structure than would cutting in the reverse direction.

This is the case because that portion of the explosive energy directed into the capsule is largely dissipated in the work of cutting the metal. Tests have shown that when the proper cutting charge is used, the resulting shock and particles traveling inward will not damage a .010-inch thick foil located 3 inches inboard of the cut. Figure 53 shows the damage received by .010-inch aluminum at various distances from a .071-inch thick aluminum plate severed by 10 grain/foot FLSC.

However, for the unusual application on this capsule, there is no advantage in cutting in an inwardly direction. The explosive charge is entirely internal to the capsule, and the "backblast" must be absorbed by the capsule structure regardless of orientation. Furthermore, there are two distinct advantages in orienting the charges in an "outward" direction:

o   The cover section to be removed is smaller in dimension than the opening in the vehicle skin through which it must travel.

o   The backblast can be used to bend the "sill" structure inward (or downward) with respect to the charge. This is better in removing any jagged edges from the path of the contents being ejected from or originating in the compartment.
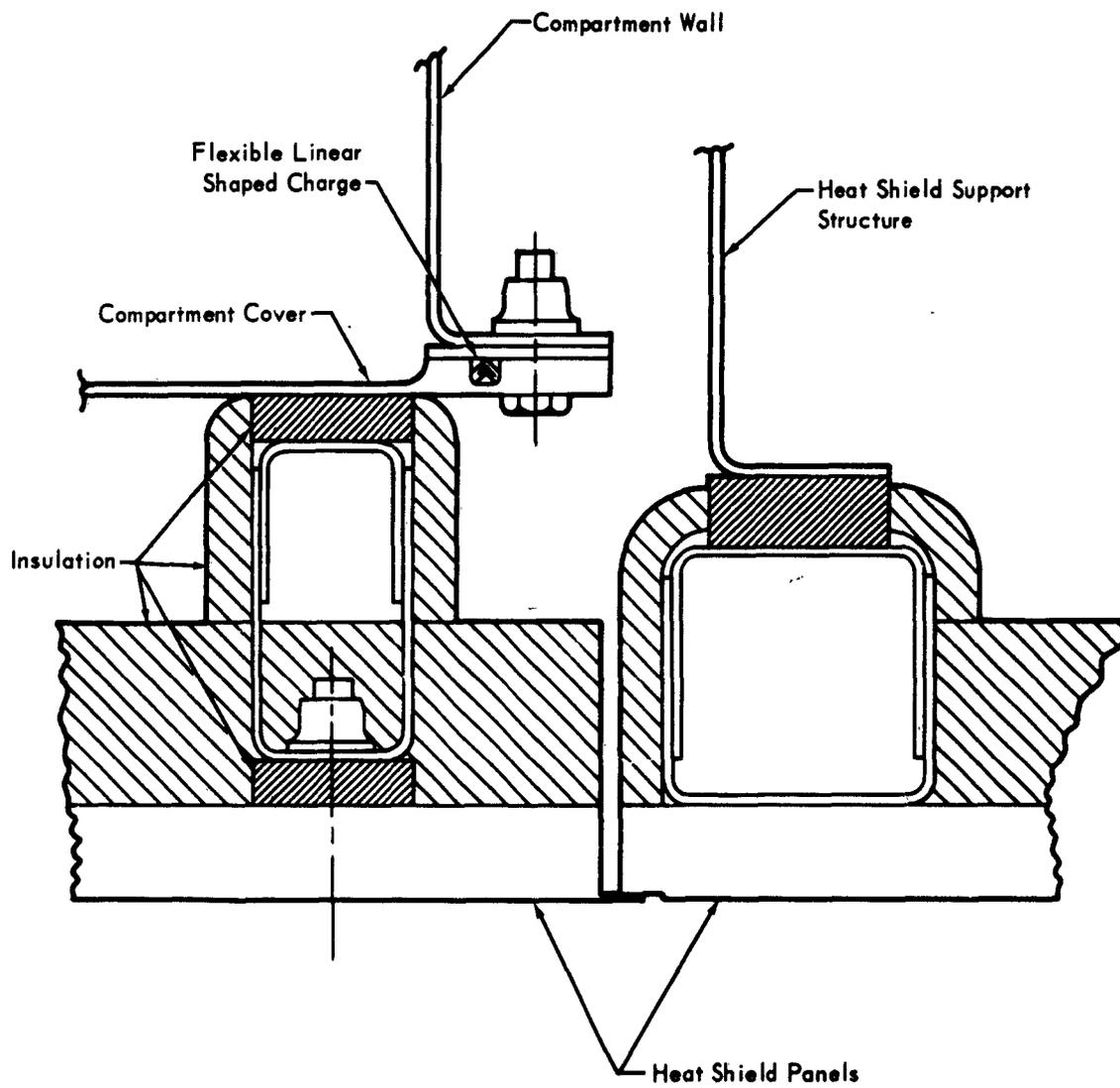
FIGURE 52   COMPARTMENT COVER REMOVAL

FIGURE 53   TEST TO DETERMINE DAMAGE FROM FLSC CUTTING

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For these reasons, the configuration shown was selected.

Each of the cover separation charges will be initiated at two points, as shown schematically in Figure 54.

The FLSC is installed in the compartment lid as was shown in Figure 52, which is a typical section perpendicular to the plane of the charge. The FLSC booster tips, as shown in Figure 55, act as relay charges to initiate the severance system, and also act to seal the ends of the FLSC. Figure 56 shows the compartment, its cover, and an initiation block, at which point the FLSC booster tips are located, and where the cover severance system receives its initiation from the SMDC stimulus transfer system. The standard SMDC end fitting and booster tip are used to initiate the FLSC booster tips. Thus, no special explosive components are required. The initiation block is inert hardware, and is the only special part needed.

(a) Design Criteria - Hatch and Compartment Cover Removers

The requirements enumerated below are considered to be the optimum design criteria for the hatch and compartment cover removal charges.

o   The FLSC shall be capable of withstanding a temperature of 400°F for a period of not less than one hour, and of meeting all performance criteria after such exposure, while at that temperature.

o   The compartment sill and any attached cut segments, when protected by the backblast cushion (if used), shall not be cut or cracked in such a manner as to weaken the basic compartment or surrounding structure, or to expose any jagged edge or surface capable of damaging the compartment contents during or after their ejection.

o   No significant or potentially dangerous shrapnel shall be formed or set free. All metallic pieces formed by the cutting action shall be retained and rigidly attached to either the compartment sill or the compartment cover. The backblast cushion, if made of a soft, flexible material, may not necessarily have to be retained per the above, but such retention should be considered a design goal.

o   The FLSC element shall be potted into, or otherwise affixed to, the cover in such a manner that normal handling, assembly, or disturbing environments (such as vibration) will not cause it to shift or be displaced from its proper position. Installation shall not damage, crack, or in any way disturb the hermetic seal of the explosive charge, or impair the cutting or propagation reliability of the FLSC.

o   Any distortion of the FLSC at the bend radii shall be minimized to the extent that the cutting ability at the bend shall not be less than that of the straight lengths of FLSC.

o   The booster cups affixed to the ends of the FLSC shall provide a hermetic seal for the explosive filler of the cup and FLSC.

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FLSC

SMDC Input "A"

SMDC Input "B"
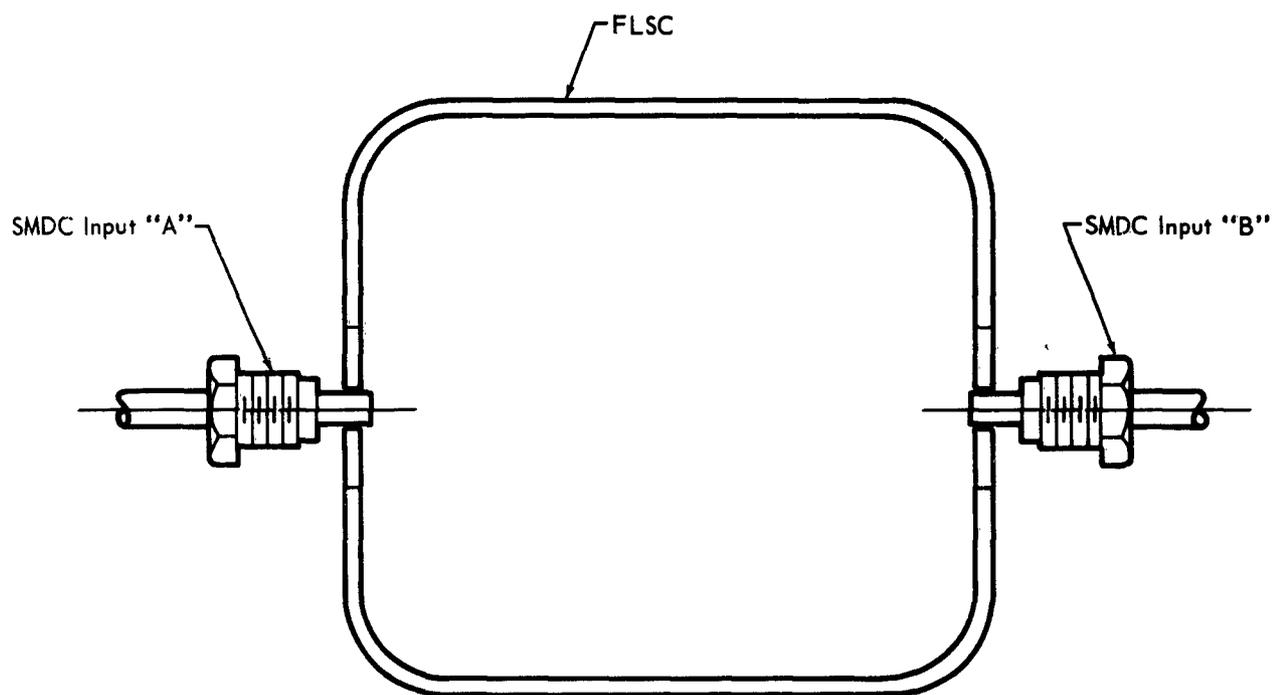
FIGURE 54   TWO-POINT INITIATION OF FLSC CUTTING CHARGES

A – A

B – B
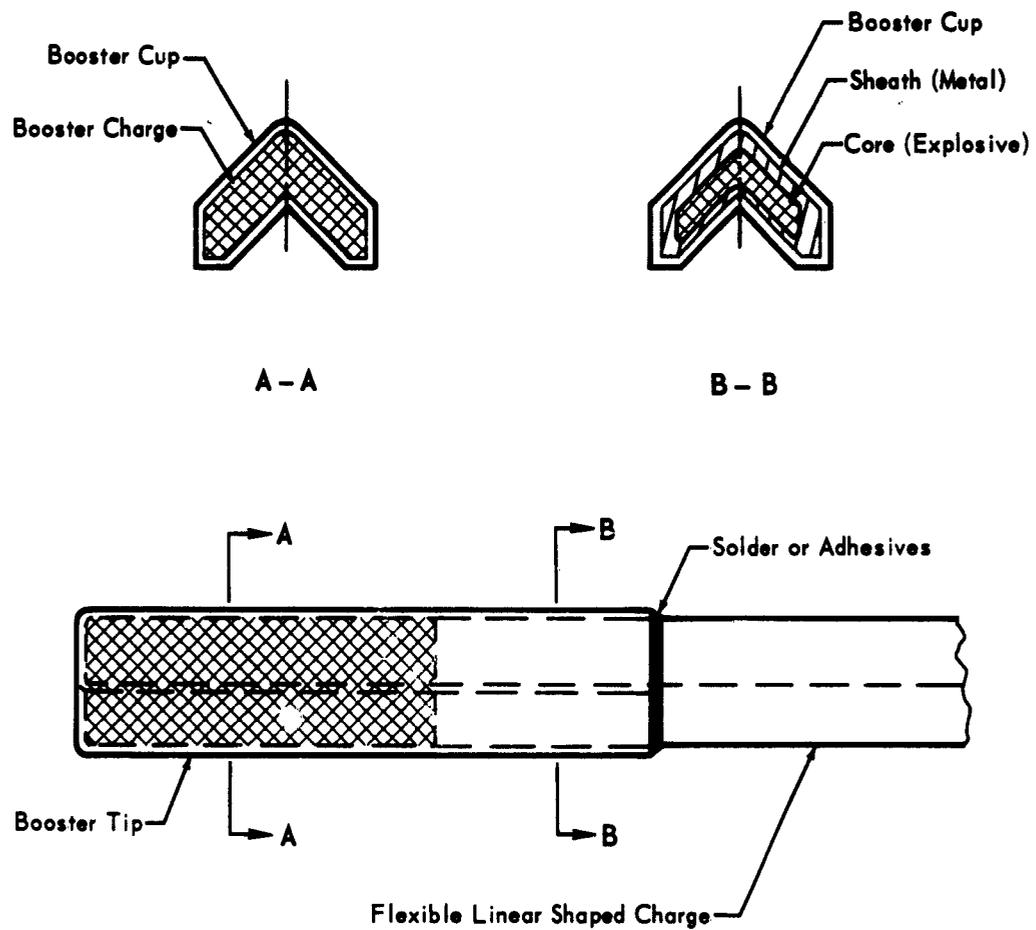
FIGURE 55   FLSC TIP
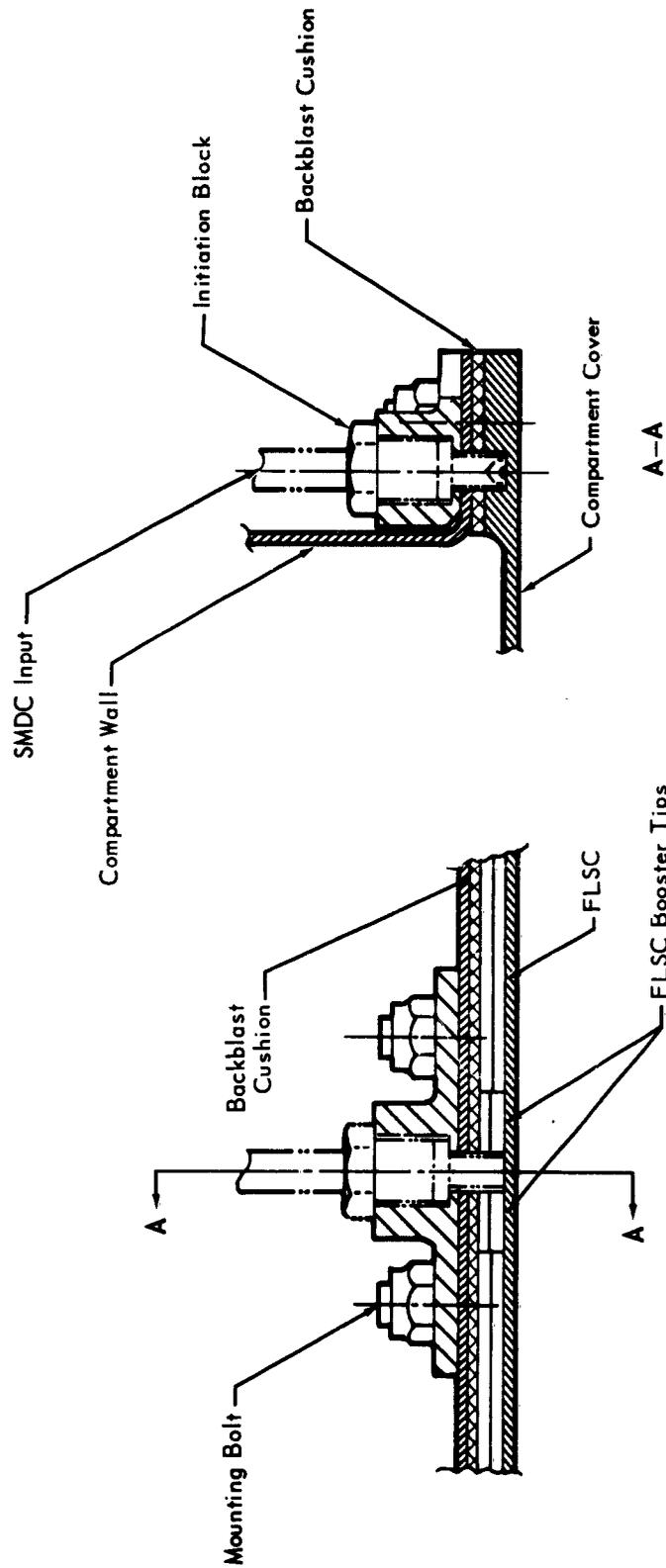
FIGURE 56 INITIATION TECHNIQUE FOR FLSC COVER REMOVAL

o   There shall be no voids, mechanical interruptions, or inclusions in
    the explosive chaige.

o   The FLSC sheath and booster cups shall be of such materials or so pro-
    tected that when assembled into the cover groove, or when the cover is
    installed on the vehicle the FLSC sheath and cup shall be protected
    against galvanic corrosion.

o   The cover severance system (FLSC/cover assembly) shall be so designed
    as to preclude the possibility of any condensation or other foreign
    material entering the groove area. If accomplished by use of low den-
    sity, closed cell foam, or any other filler material, all cutting tests
    shall be performed with said filler used in the test specimens.

o   Reliability of initiation of the FLSC by the standard SMDC booster tip
    and back-initiation of the SMDC tip from the FLSC boosters shall, as
    proved by established and acceptable methods, be compatible with the
    overall reliability requirements of the escape system (reliability of
    .99995 at 80 per cent confidence level can be established if proper
    test methods are selected).

o   The FLSC shall be capable of completely cutting the covers with a
    reliability compatible with the overall system reliability requirements.
    The tapered plate test procedure shall be used, with mounting provi-
    sions equivalent to the actual installation, and with all tests per-
    formed at the temperature within the operating temperature range which
    yields the least efficient cutting action. By this method, reliability
    of .9995 at 80 per cent confidence level can readily and economically
    be established.

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2.3.4 Windshield Cover Release and Removal Subsystem

2.3.4.1 General

During re-entry, the upper surfaces of the glide re-entry vehicle encounter sufficient aerodynamic heating that it is necessary to protect the windshield by means of a cover or heat shield. This also is true for an escape capsule re-entry when a flight is aborted in any of the high-altitude/high-velocity modes.

A study of the escape capsule layout will reveal that just ahead of the windshield are the suspension points for the parachutes, both drogue and main, and the compartment wherein the main parachute is stored. It is advisable, from the standpoint of both thermal protection and the maintenance of a smooth mold line, to use the same windshield cover to protect this entire region.

During a normal flight of the parent vehicle, it is necessary to jettison this cover as soon as possible after maximum re-entry heating, not only for psychological reasons but also to assure the maximum possible vision for the pilot to make a correct landing approach. It follows that this cover must be jettisoned on each flight, and, therefore, a release-and-jettison system which affords the maximum operating reliability with the least possible damage to the capsule is required.

Satisfactory operation of the windshield cover release and removal system is also essential to the abort system since, as mentioned previously, some of the parachute suspension points and the main recovery chute are located beneath this cover.

From the foregoing, it is obvious that reliability is the foremost design criterion for the windshield cover removal subsystem.

Finally, because this area also serves as the most convenient and practical access to the forward portion of the capsule interior, it also is desirable that the cover be easily removed or attached, and be one of the last items to be secured prior to launch.

The schematic drawing of the selected windshield cover release and removal subsystem is shown in Figure 57. It provides for electrical initiation of the subsystem, and SMDC stimulus transmission within the system. This assures the best possible degree of simultaneity in the functioning of redundant items. Each of the electric initiators is of the type defined and specified in Section 2.2.3.1(f).

The windshield cover release mechanism is actuated by redundant SMDC initiated PAD, either of which will operate the entire release mechanism. It is considered desirable to provide integral with the PAD system, alternate means to easily release or secure the cover by use of pneumatic pressure. This alternate method of operation is for use by ground service personnel prior to launch of the vehicle.

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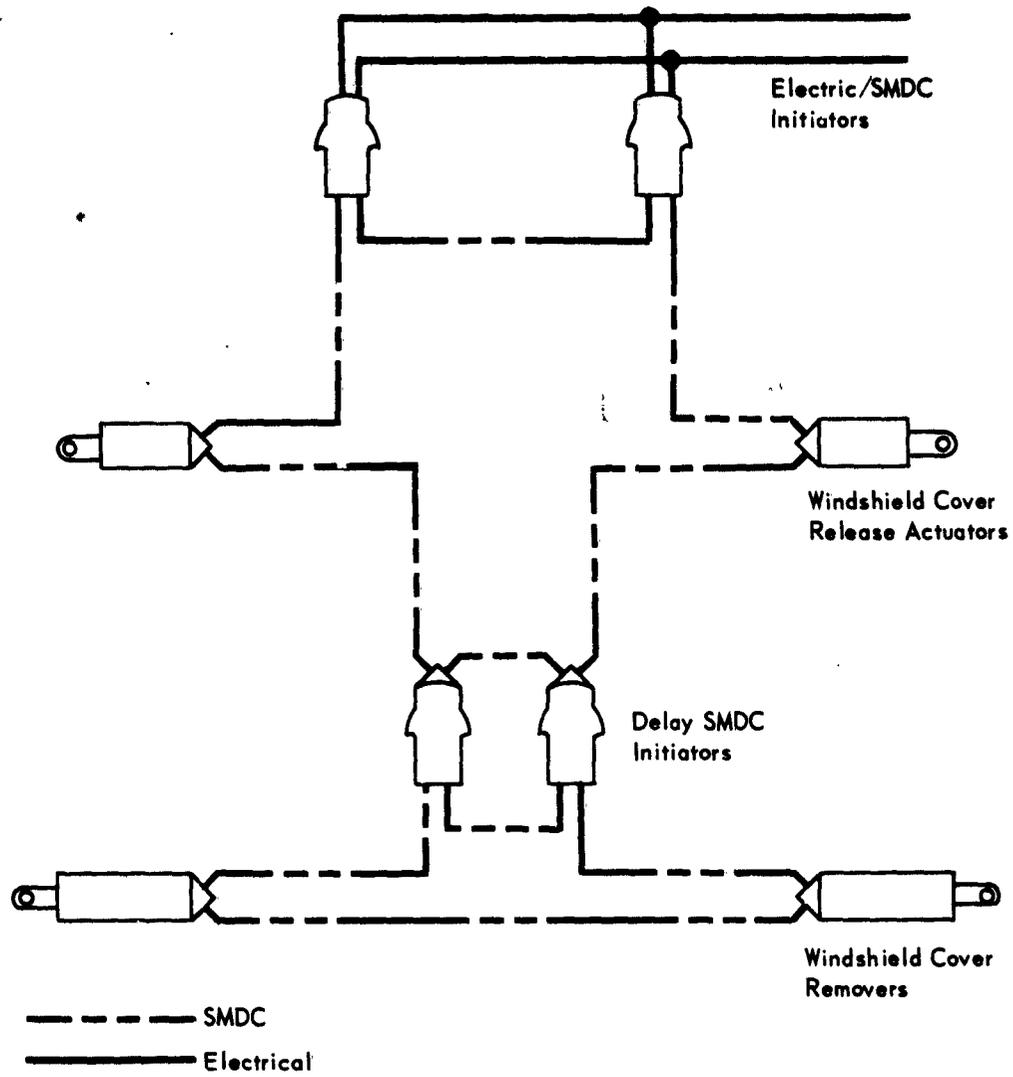
FIGURE 57   WINDSHIELD COVER RELEASE AND REMOVAL SUBSYSTEM

Electric/SMDC Initiators

Windshield Cover Release Actuators

Delay SMDC Initiators

Windshield Cover Removers

– – – – – SMDC

——————— Electrical

Simultaneously with the initiation of the release actuators, redundant delay initiators (SMDC input/SMDC output) are also fired. The delay is incorporated to assure that the cover is fully unlocked before the removers start their action. Whichever delay initiator produces its output impulse first initiates both cover removers.

Two removers, one on each side of the main parachute compartment, are used. Normally they would act in tandem in jettisoning the cover, but either should be capable of accomplishing this function.

2.3.4.2 <u>Cover Release Actuators</u>

There are several alternative approaches for the design of a cover release system to meet the requirements discussed above. These include the following:

o   Explosive bolts

o   Separation nuts

o   MDC "bolt popping"

o   FLSC severance

o   Mechanical unlatching linkage

Regardless of the method of cover release selected, a positive form of jettison device (canopy remover) will be required for this application because of the existance of a positive or holding pressure against the cover at some angles of attack which will be encountered. Also, in a normal flight mission the cover must be forcefully thrown clear of the command module. Thus, whether the severance or release system would impart any momentum to the cover can be disregarded as a factor in the selection of the best technique.

The relative merits of the first four of the above listed techniques were covered quite thoroughly in Section 2.3.3.3, "Hatch and Compartment Cover Removal," and that comparison is applicable here. Basically, for this application, the first two, explosive bolts and separation nuts, can be eliminated from consideration for two reasons; the large number required would lead to a reduction in system reliability, and they would not provide the desired feature of rapid and convenient attachment and release of the cover. MDC bolt popping would not function satisfactorily because of the high cover weight, and also would not meet the "quick attach and release" design goal. FLSC cutting would have very high reliability but the charge would have to be buried well inside the skin and be well insulated. Therefore, the normal point of attachment and removal would have to be separate from the attach points near the FLSC. Even then, a number of individual screws would have to be used, thus the goal of convenience in manual attachment or release would not be fulfilled. In addition, some damage to the capsule would be almost a certainty each time the system was fired.

All things considered, a mechanical latching/unlatching system appears to be the optimum method for a number of reasons.

o   By using a basically mechanical system, a single PAD can be used to operate the entire system.

o   There is no problem in using dual PAD for redundancy, thus enhancing reliability. The PAD can be sufficiently small that the weight penalty is minimal.

o   A secondary means of actuation, for example a pneumatic system, can be used for the ground service installation and removal.

o   Servicing, i.e., installation and removal, is quick and convenient.

o   Actuation will not damage the capsule.

o   The system is the safest for servicing personnel.

o   It is more compatible with a secondary method of actuation for use by servicing personnel.

(a) Design Criteria - Cover Release Subsystem

The following criteria are considered essential to an optimum windshield cover release subsystem.

o   The cover release subsystem shall consist of a series of latches, all actuated from a common actuating point.

o   Two pyrotechnic actuators shall be used, either of which shall be capable of operating the release mechanism.

o   An auxiliary means of operating the release mechanism shall be provided to permit prelaunch installation or removal of the cover without disturbance of the PAD system used for inflight operation of the system.

o   The release mechanism shall not be damaged by functioning, nor shall it in any way damage the capsule by said functioning, whether actuated pyrotechnically or by the auxiliary means.

o   The PAD used to actuate the release mechanism in flight shall be initiated by the standard SMDC output.

(b) Windshield Cover Release Design

Figure 58 shows, in preliminary form, the design selected for the cover latching system. At each of the latching points an overcenter toggle latch engages a matching lug to hold the cover in place. All the toggle linkages on both sides of the cover are actuated by a single actuating lever located centrally on the forward bulkhead of the pressure cabin,

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through appropriate tie links. All tie links will be of tubular construction for the maximum strength/weight ratio.

While any type of actuators desired may be used for both the pyrotechnic and the auxiliary (servicing) actuators, those described in the ensuing paragraphs are considered to be most desirable. First, however, it may be well to mention one requirement which results from the type of latch shown. The actuating force required to unlock the overcenter linkages is initially quite high, but after the links pass the on-center position, the force required rapidly drops to zero. Furthermore, because of the inertia of the linkages, a controlled deceleration of these masses is highly desirable. Thus, viscous snubbing of the system is required; viscous, rather than mechanical, because of the requirement for repeated functioning.

Two modes of actuation are required, one pyrotechnic and one which can be manual, hydraulic, pneumatic, or by any other means convenient to servicing personnel. Pneumatic actuation was chosen as the most convenient and most readily available means.

Consideration was given to several configurations, including the incorporation of propellant and pneumatic actuation and hydraulic damping all in a single unit, but it was concluded that by dividing the functions between two units the overall system would be simpler, less expensive, and more reliable.

Figure 59 shows the two actuators to be used for operating the latching mechanism. Figure 59 (a) is the PAD which serves a two-fold function. Application of pressure from compressed gas (e.g., nitrogen) to the back side of the piston latch is the cover after installation. Initiation of the cartridge from the SMDC stimulus transfer system previously described, unlocks and releases the cover. This is the normal mode of operation in flight.

Figure 59 (b) shows the combination snubber-pneumatic unlock actuator. For ground servicing of the capsule, the application of gas pressure (again N_2) to the left-hand side of the piston unlocks the cover. The hydraulic damping system shown on the right-hand end of the device serves to snub the motion of the linkages when the mechanism is being unlocked, regardless of power source. After a relatively free initial stroke, the tapered metering pin enters the orifice, gradually providing more and more restriction to motion, and thus decelerating the entire mechanism to prevent it's slamming home at the end of its stroke.

For reliability, two PAD actuators will be used, either of which will be capable of releasing the windshield cover. Only one snubber is required.

Overall arrangement of the various actuators, the snubber, and the mechanical bell crank is shown in Figure 58.

Actuators

Snubber

Windshield Cover

Cano
(2 Re

Cabin Wall
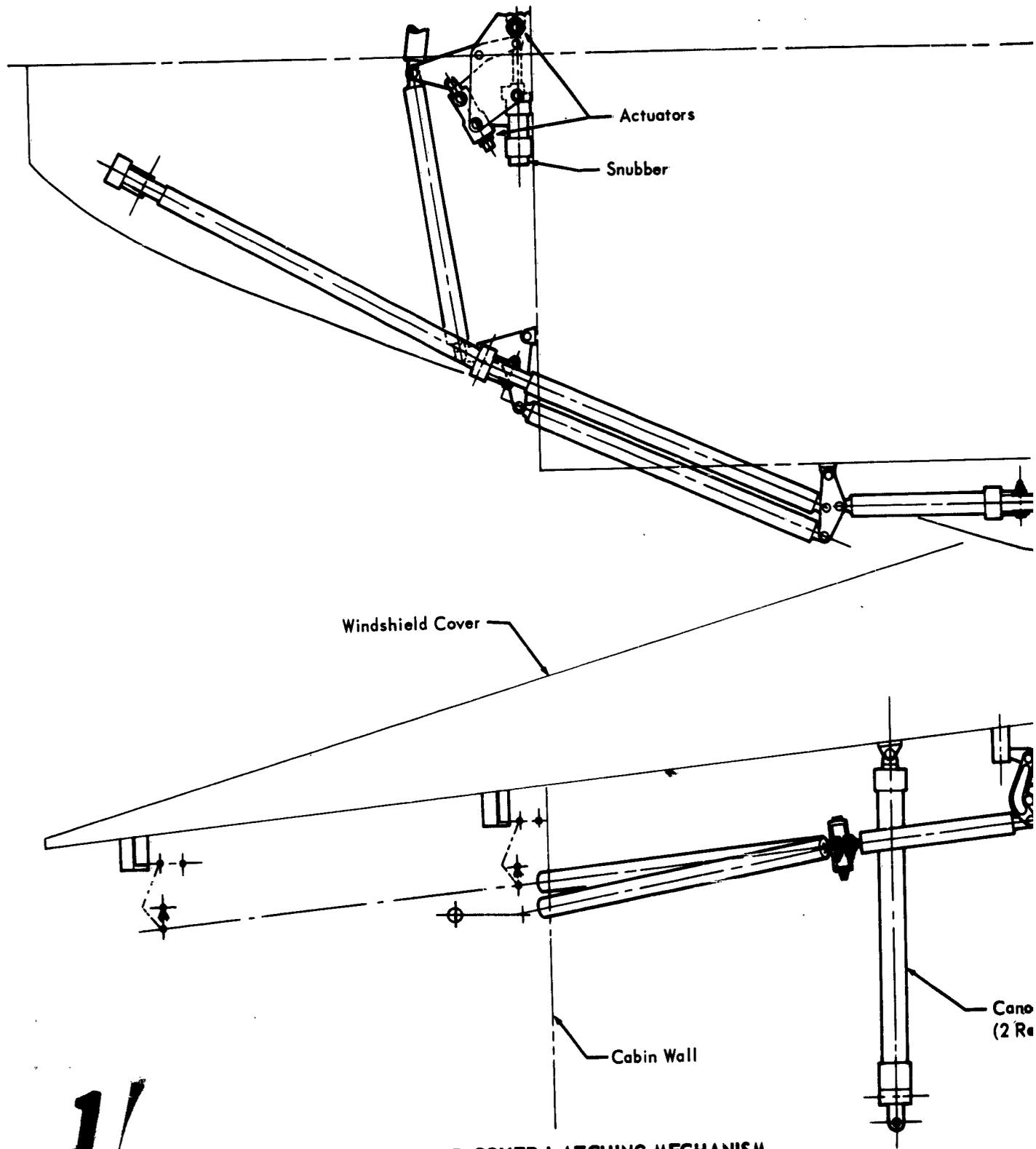
FIGURE 58 WINDSHIELD COVER LATCHING MECHANISM

Actuators

Snubber

Windshield Cover

Cover

Over-Center Latch

Canopy Remover
(2 Req.)

Cabin Wall

D COVER LATCHING MECHANISM

2

MDF Tip Receptacle

N₂ Port (Cover Lock)

(a)
Actuator

N₂ Port (Cover Unlock)

Hydraulic Fluid
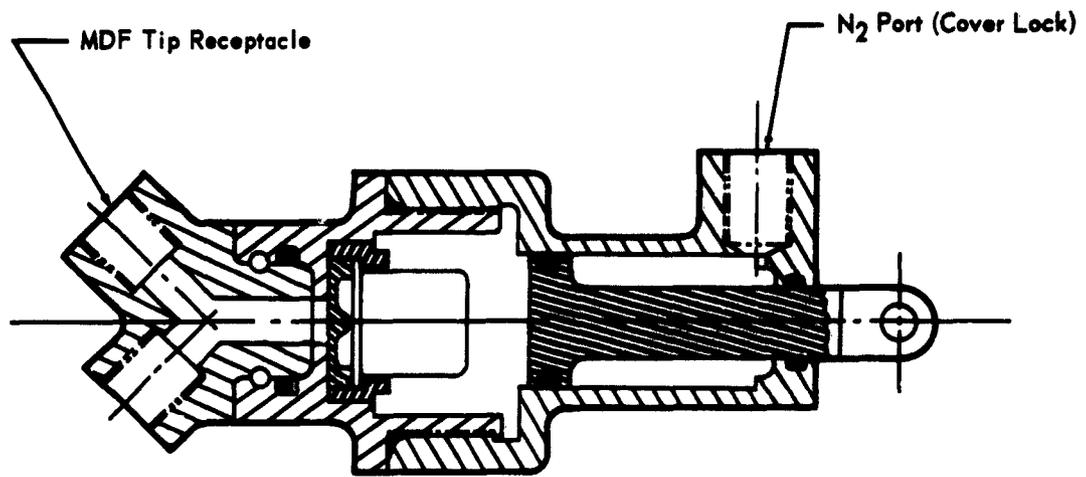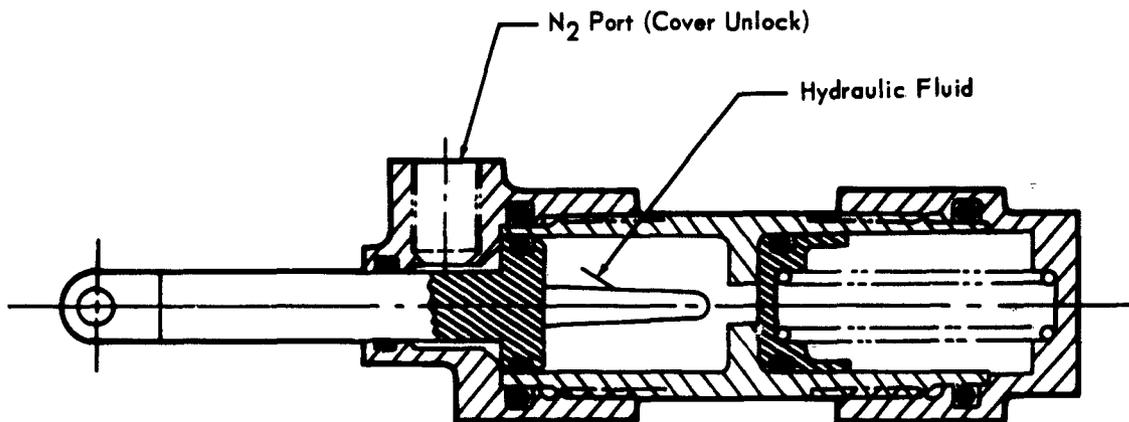
(b)
Snubber

FIGURE 59 WINDSHIELD COVER UNLOCK
ACTUATOR & SNUBBER

2.3.4.3 Windshield Cover Removers

Basically there are several ways in which canopies, which are not unlike the windshield cover described herein, can be removed. These include the use of spring-loaded actuators, pneumatic actuators, the MDC "bolt popping" technique, and the conventional propellant actuated remover. In this instance, where the actual canopy is between the cover and the personnel, even one or more small rocket motors could be used for this purpose.

The spring-loaded and pneumatic actuators were rejected in this case as being heavier and/or bulkier than the PAD-type. As previously explained, the MDC system (and also the use of FLSC), only works well with light covers; the cover involved here is far too heavy, and the aerodynamic loads too high, to rely on this method of severance and separation. Also, some sill damage almost invariably occurs, and for a reusable vehicle this is an important drawback. The use of small rocket motors was carefully analyzed, but the possibility of damage to the other components (windshield, parachute risers and attachments, and the main chute itself) was a deterrent to their use. Also, the degree of control over the cover trajectory which could be obtained by use of a propellant actuated remover was considered to be a strong point favoring its use.

The design of a propellant actuated cover remover to meet the general performance requirements is straightforward, and can follow accepted practice with a solitary exception; because the remover is in relatively direct contact with the hot "skin" of the cover, it must be insulated from this skin and/or must have a sufficient heat sink or cooling system incorporated into it to protect the propellant from overheating.

The removers need not, and indeed should not, lock in their prefire position, and the piston or tube, whichever is the moving member, should come free of the end of the stroke.

(a) Design Criteria - Windshield Cover Remover

The following design criteria should apply to the windshield cover removers used in this subsystem.

o   Each remover shall be powered by a removable and replaceable cartridge, and the cartridge and firing head shall be designed to be initiated by either of two standard SMDC stimulus transfer lines; or

o   Each remover shall be powered by two removable cartridges, each of which shall have its own standard SMDC initiation line, and either of which shall ignite the other.

o   The cartridges shall be capable of replacement without the use of special tools.

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o   Each remover shall have developed at least 70 per cent of its
    average thrust within .020 second after receipt of the firing
    stimulus, and when fired against the most probable combination
    of dynamic and static loads, the thrust throughout the stroke
    shall be as uniform as possible.

o   The removers shall incorporate sufficient heat-sinks and/or
    means of cooling that the performance of the propellant load
    shall not be impaired when the remover is subjected to the
    same heat flux input as will be experienced in the maximum
    heating trajectory for a period 1.5 times the duration of that
    trajectory.

o   The cartridges shall be sealed such that they are independently
    capable of withstanding all environmental conditions which shall
    be encountered during storage without any supplementary protec-
    tion, and all flight environmental conditions except temperature
    without reliance upon the seals of the remover.

o   The remover shall be so sealed as to protect the enclosed cart-
    ridges from all flight environment conditions for the duration
    of the mission, from launch to cover jettison.

o   Either remover, independently, shall have sufficient power to
    successfully jettison the windshield cover from the escape cap-
    sule under the worst combination of aerodynamic and inertial
    loads.

o   Both removers, working in tandem, shall be capable of success-
    fully throwing the windshield cover clear of the combined cap-
    sule and command module (glider configuration) under the worst
    combination of dynamic loads, without imparting structural
    damage to the parent vehicle.

(b) Selected Design

The selected design for the windshield cover remover is shown in
Figure 60. Although conventional in basic design, it represents
several departures from tradition in details. These features are in-
tended to cope with the unique thermal problem characteristic of, but
limited to, those PAD which contact the outer skin of the capsule or
which are likely to be less insulated from this skin. For example,
any drag flaps which might be required could advantageously utilize
these or similar techniques for protecting their propellant charge.

This thermal protection is afforded the cartridge by use of two basic
techniques:

o   The use of a heat sink at or near the source of the incoming heat
    flow.

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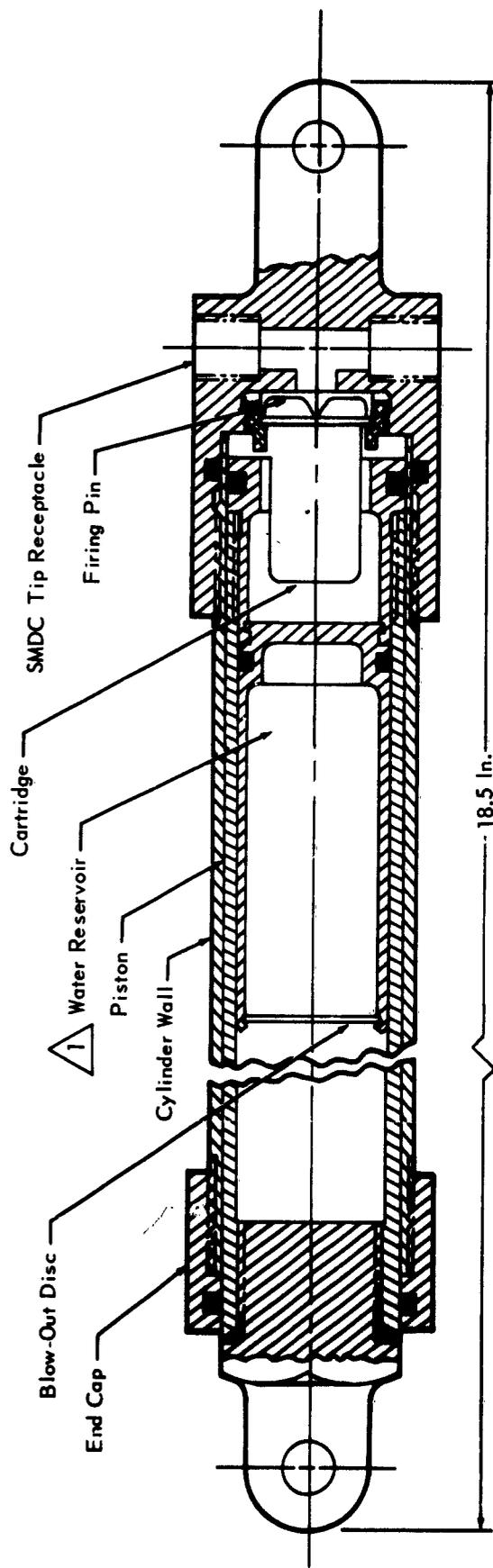
FIGURE 60 WINDSHIELD COVER REMOVER

Firing Pin

SMDC Tip Receptacle

Cartridge

Water Reservoir

Piston

Cylinder Wall

Blow-Out Disc

End Cap

⚠ 1 Water Reservoir

18.5 In.

⚠ 1 Water used as heat sink.

o   The use of latent heat of vaporization of a liquid or solid
        whose boiling point or sublimation temperature is slightly below
        the safe temperature for the propellant used, and located as
        close as possible to the propellant cartridge.

Beryllium was chosen as the heat sink because, of the various materials
which might be practically applied to this purpose, it had the highest
specific heat. It is located near to the source of heat for two
reasons:

o   At this location it can be allowed to reach a much higher tempera-
        ture than it could if it were near the propellant.

o   By reducing the heat flux to all components below it in the
        direction of heat flow, it helps to limit the temperature of all
        these parts.

The "water cartridge," located inside the inner tube (or hollow piston)
serves several purposes:

o   It provides a high capacity source of cooling for the area near the
        cartridge (970 Btu/pound for heat of vaporization of water at 212° F
        alone, plus the possibility of heating the resulting steam).

o   It aids ignition, by limiting the free volume seen by the cartridge
        until a predetermined pressure is attained, while at the same time,
        once the lip of the water cartridge shears off, it acts as a
        damped (pneumatic spring) piston, increasing the free volume of
        the remover, and thus providing a smoother pressure time trace.

o   In the event of "lock-shut" firing, this same action permits the
        use of the maximum available free volume, thus permitting a lighter
        construction for the unit.

2.3.5 Recovery Subsystem

2.3.5.1 General

The various functional and component requirements of the recovery system were thoroughly covered in Part I of this report. Further system analysis, as reviewed in Section 2.1 of this volume, indicated that no major changes from the preliminary system concept are necessary.

Basically, the components required may be grouped according to the functions which they perform. In these groupings, however, the associated initiators and switches can be omitted, or mentioned in passing, since they have already been thoroughly covered in Section 2.4.1. Classified as above, the functions and their associated components are as follows:

o   Drogue Chute Deployment - drogue mortar

o   Drogue Chute Reposition, and Drogue and Main Chute Releases - one or more riser release devices for each of the above functions

o   Main Parachute Deployment - accomplished, depending on escape mode, by one of two techniques: in most modes, by the drogue chute release or disconnect; in modes G/H by means of a thruster/catapult. Also requires an "apex line" cutter.

o   Main Chute Disreef - several reefing line cutters

o   Miscellaneous - several barostatic switches, a pressure actuated switch, an impact switch, and an intervalometer

A schematic drawing of the recovery subsystem is shown in Figure 61. The sequencing of the various devices in the subsystem can be derived, for the two basic recovery modes, from Figure 4, and has been described in Section 2.1.3 for each individual escape mode; however, it is desirable to analyze the two recovery modes in detail to understand some of the redundancies provided to enhance the overall reliability.

But first it may be well to point out that the primary method of stimulus transmission and initiation throughout this subsystem is electrical. The reasons are twofold:

o   The delay between operations varies not only as a direct function of time, but also depends on altitudes; thus, a number of interruptions occur in the operation. Electrical systems can be handled under these conditions, not only more easily, but also far more reliably, than an explosive stimulus.

o   Alternate sources of initiation, of either components or groups of components, can be provided more frequently, more easily, and at a far smaller weight penalty than a mechanical/explosive initiator. Furthermore, it may be desired that some of these alternate initiation stimuli come from the ground control system; these, of necessity, would have to be electrical.
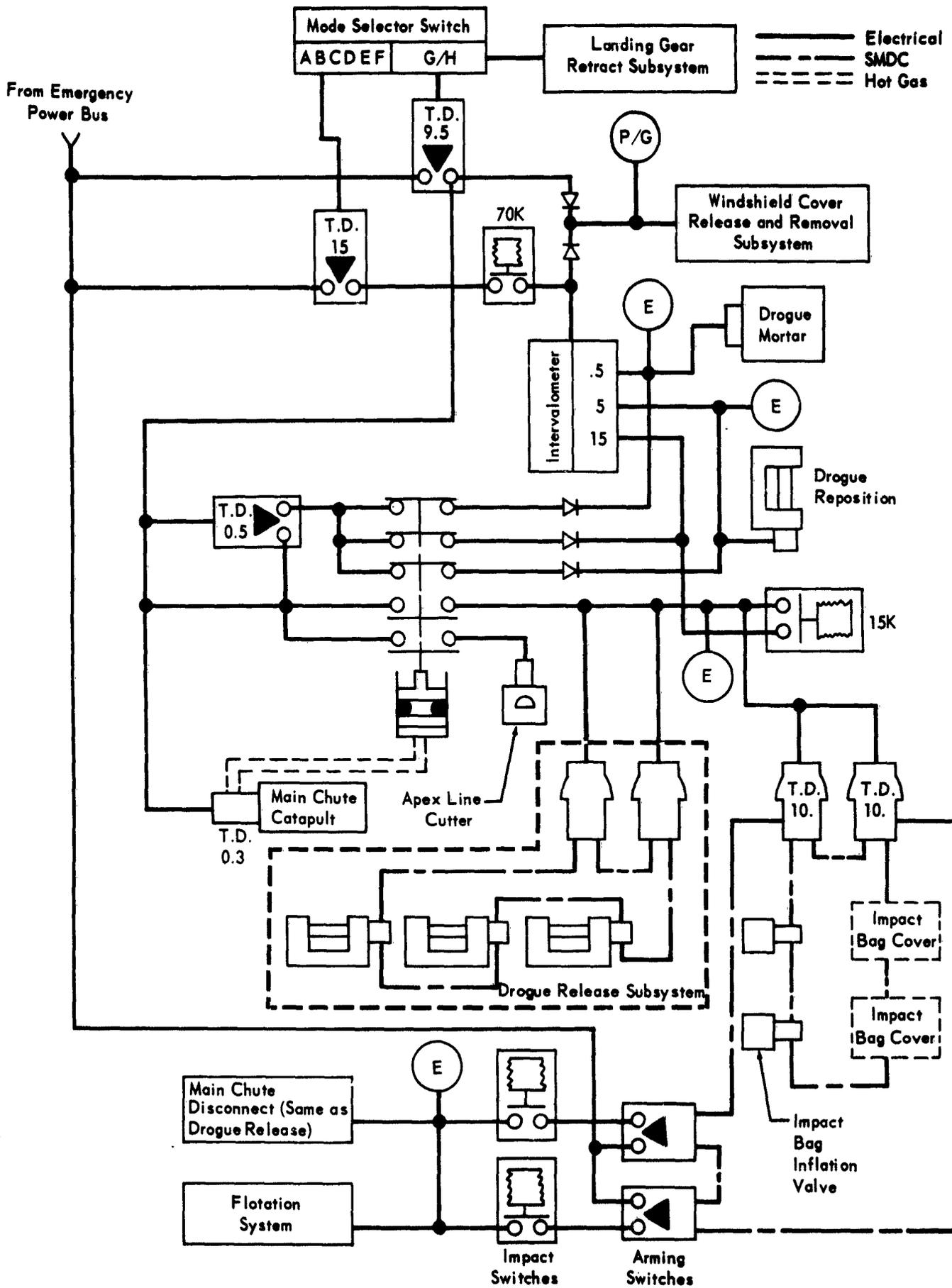
FIGURE 61   RECOVERY SUBSYSTEM

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Wherever electrical initiation is used, dual bridgewire initiators are employed. Each of the two bridgewires are on separate circuits, and when interrupts, either pyrotechnic or barostatic switches, are employed, two independent and redundant devices are used, each one closing both, and where appropriate, fired by either and both of the parallel bridgewire circuits. For clarity, this is not indicated in the schematics, but it should be remembered when the system reliability is analyzed.

(a) Subsystem Sequencing - Escape Modes A through F

For escape modes A through F, functioning and sequencing of the recovery system is identical. The path is indicated in Figure 62. The initiating stimulus enters the subsystem through the mode selector, and initiates a 15-second delay switch. After an elapsed time of 15 seconds, the switch closes, relaying the electrical power to the 70,000-foot barostat. When the barostat closes (or if it is already closed) the power is transmitted to two devices: (1) through a diode to the windshield cover release and removal system, and (2) to the recovery system intervalometer. The intervalometer, once started, supplies power at various time intervals to other PAD as follows:

o   .5 second - to drogue mortar, ejecting drogue chute

o   5 seconds - to drogue repositioner

o   15 seconds - to 15,000-foot barostat

The 15,000-foot barostat is used to regulate the altitude at which the main parachute is deployed. This chute is deployed by releasing the drogue chute, which by means of a line attached from the drogue chute risers to the apex of the main chute, pulls the main chute from its compartment. Deployment of the main chute automatically initiates several 2.5-second delay reefing line cutters, thus dereefing the chute after that elapsed time.

Simultaneously with the deployment of the main chute, a 10-second pyrotechnic delay initiator is ignited. After this elapsed time, the impact attenuation system is initiated, and a zero delay arming switch is actuated. This switch arms an impact switch which, on the decelerations experienced on landing, actuates the main chute disconnects and the flotation system.

(b) Subsystem Sequencing - Modes G/H

In modes G/H, the deployment of the main parachute is time critical, due to the proximity of the glider to the ground at the time of abort. In these modes, there is not sufficient time for use of the normal drogue-main sequencing, so a catapult is used to directly deploy the main chute. The stimulus-sequencing path is indicated in Figure 63.

The stimulus, entering through the mode selector, initiates a 9.5-second time delay switch which, after the elapsed time, relays the electrical firing stimulus to several PAD. Firstly, current passes through a diode and
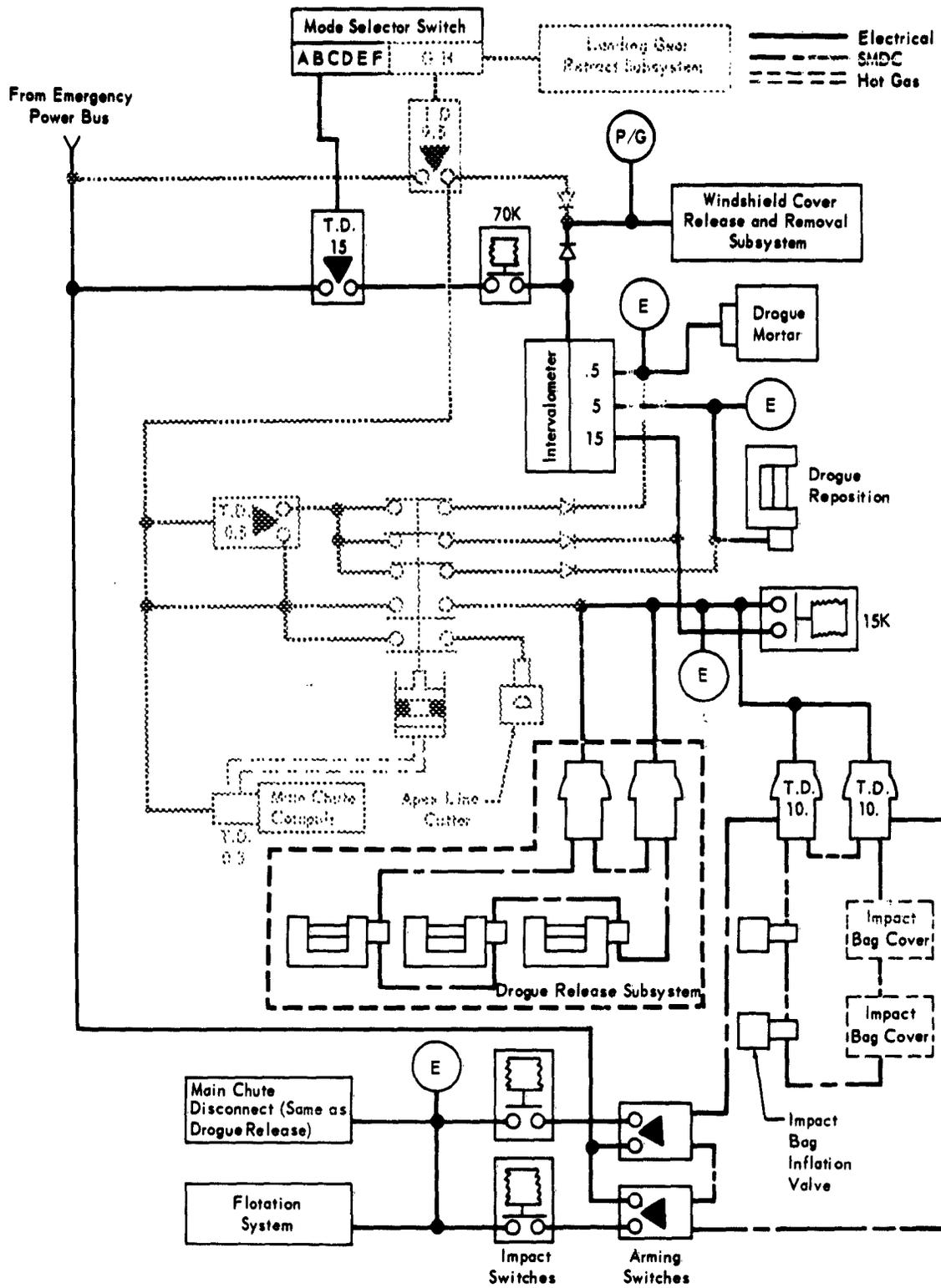
FIGURE 62 RECOVERY SUBSYSTEM UTILIZATION – MODES A/F
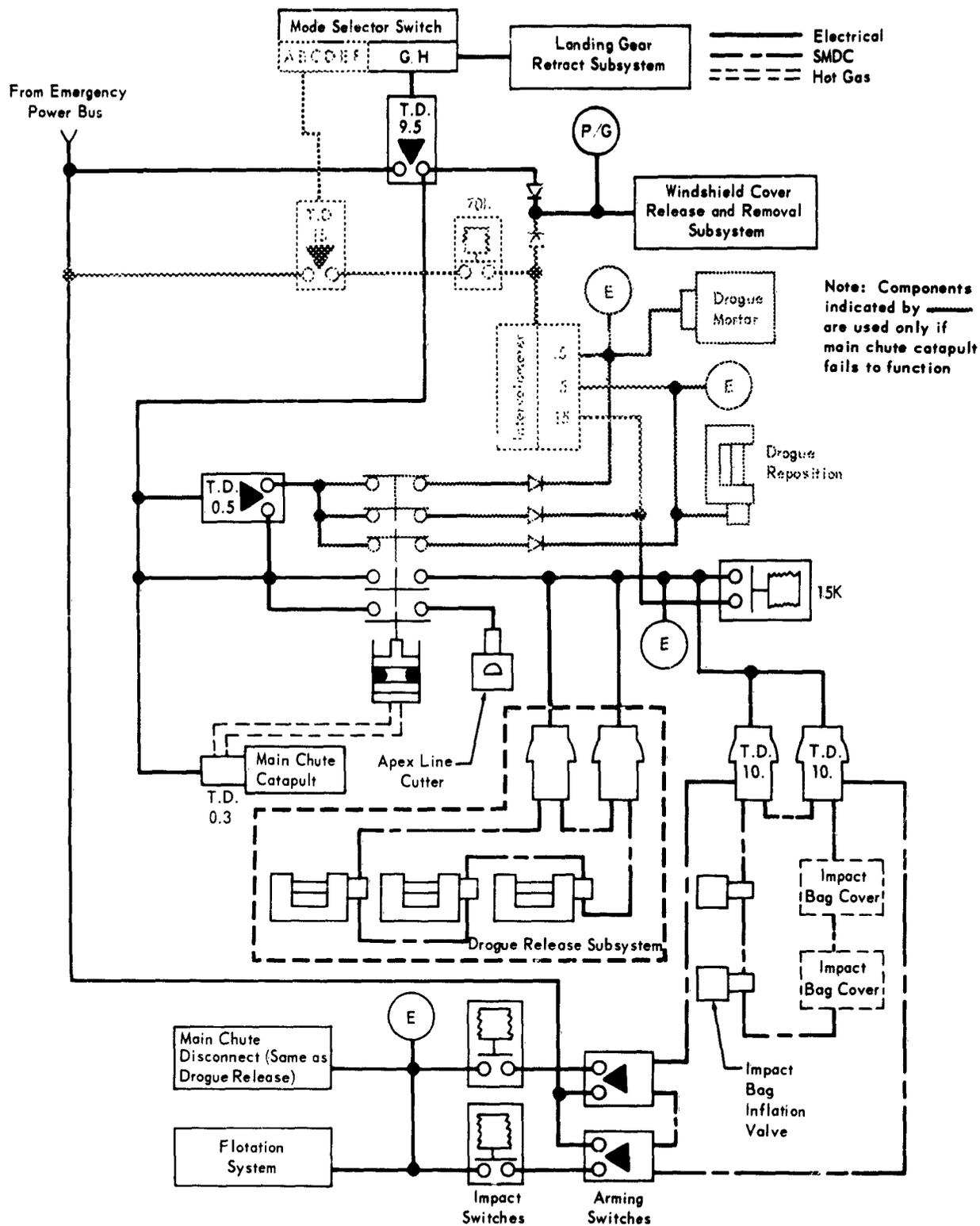
FIGURE 63 RECOVERY SUBSYSTEM UTILIZATION – MODES G/H

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initiates the windshield cover release and removal system. Secondly, it initiates a 0.5-second pyrotechnic delay switch; simultaneously, it initiates an 0.3 second delay cartridge in the main chute catapult.

After the required 0.3 second, the catapult propellant charge is ignited, and the catapult starts to stroke. The buildup of pressure in the catapult operates a 5-pole pressure switch (3 poles N.C., 2 poles N.O.). Opening of the 3 normally closed poles electrically disconnects the 0.5-second delay switch mentioned above. Closing of the 2 normally open poles in this switch transmits the firing stimulus to the drogue releases (merely for simplicity of the system); to the apex line cutter, thus severing the connection between the undeployed drogue and the deploying main chute; and initiates the 10-second time delay initiator which operates the impact attenuation system and the arming switch for the flotation system, as previously discussed.

Should the main chute catapult fail to fire, the pressure in the catapult would not develop, and thus the 5-pole pressure switch would not be operated. In this event the 3 normally closed poles would remain closed. Thus, after an overall elapsed time of 0.5 seconds, the pyrotechnic switch would close, simultaneously firing the drogue mortar, the drogue repositioner, and (through the closed 15,000-foot baroswitch) the drogue release, as well as the delay initiator for the impact system, etc. The above combination of delay and pressure switches provides a backup to the main chute catapult whereby, should it fail to operate, the drogue chute is used, without any delays, as a pilot chute for the extraction of the main chute. It is expected that in most, if not all, cases the backup system would provide full deployment of the main chute in time to safely recover the escape capsule.

2.3.5.2 Drogue Chute Deployment

There are three principle methods by which drogue chutes can be deployed. These are by means of a drogue gun, a drogue mortar, or a thruster. In the case of the drogue gun, the drogue chute in a packed condition is attached to a heavy metal slug by means of a line. A cartridge is used as the expelling charge for the slug, which, when fired, pulls the drogue chute out until it is deployed.

The drogue mortar is much larger than a gun itself but since the drogue chute actually is packed inside the mortar tube of the device, considerable space savings are effected. In addition to an expelling cartridge the other major component of the mortar is the sabot. This sabot or shoe is positioned at the bottom of the mortar tube with the drogue chute directly on top of it. When the drogue mortar is fired, the expanding gases force the sabot forward, which in turn pushes the chute out.

The third method utilizes the principles of a thruster, with the drogue chute packed in a pan mounted to the top of the thruster, the results of which are similar to the mortar in that the chute is pushed out. It differs from the mortar in that the device usually is buffered at the end of the stroke, so that all moving parts are retained within the device.

Because space and weight are limiting design parameters in this system, both the drogue gun and the thruster methods of deployment must be ruled out, either on the basis of weight or the volume required. Only the drogue mortar offers the optimum of a compact design and the lowest weight of all three methods available.

(a) Design Criteria - Drogue Mortar

In addition to the environmental requirements outlined in the Appendix, the drogue chute mortar must meet certain operational requirements, paramount of which are:

o   The drogue chute shall be ejected with sufficient velocity to be com-
     patible with the overall requirements of the recovery subsystem.

o   The seal between the sabot and the mortar tube shall be such that a
     gas tight seal is maintained during functioning of the device, and un-
     til the sabot clears the mortar tube.

o   The general design of the sabot itself shall be such that the drogue
     chute is fully protected from damage due to hot propellant gases that
     might otherwise envelop it, when the sabot clears the mortar tube.

o   The cartridge housing shall be designed to accept two electrically
     initiated pressure cartridges.

(b) Selected Design

The selected design of the drogue mortar is shown in Figure 64. The device is initiated by redundant cartridges located in a cartridge housing, which vent into an initial fixed air space below the sabot. This volume is main-tained by the incorporation of a cylindrical spacer at the lower end of the sabot. The sabot must be a tight tolerance fit to the bore of the mortar to preclude any chance of the sabot cocking in the bore and jamming. The actual gas seal between the sabot and the bore is obtained by the use of an O-ring at the base end of the sabot.

2.3.5.3 Drogue Chute Reposition and Drogue and Main Chute Release Devices

As discussed in Volume 1, it is necessary to provide a device to release the drogue shrouds from their attachment point on the aft bulkhead of the pressure cabin, and allow the capsule to reposition such that it is suspended from three points forward of the cabin just over the main chute stowage com-partment. In addition, three drogue release devices must be provided which upon operation will allow the drogue to deploy, via the apex line, the main parachute. Following impact, the main chute shall be disconnected to prevent surface winds from dragging or rolling the escape module. Since all of the described operations represent disconnect-type functions, the same design principles and criteria will be used for each device.
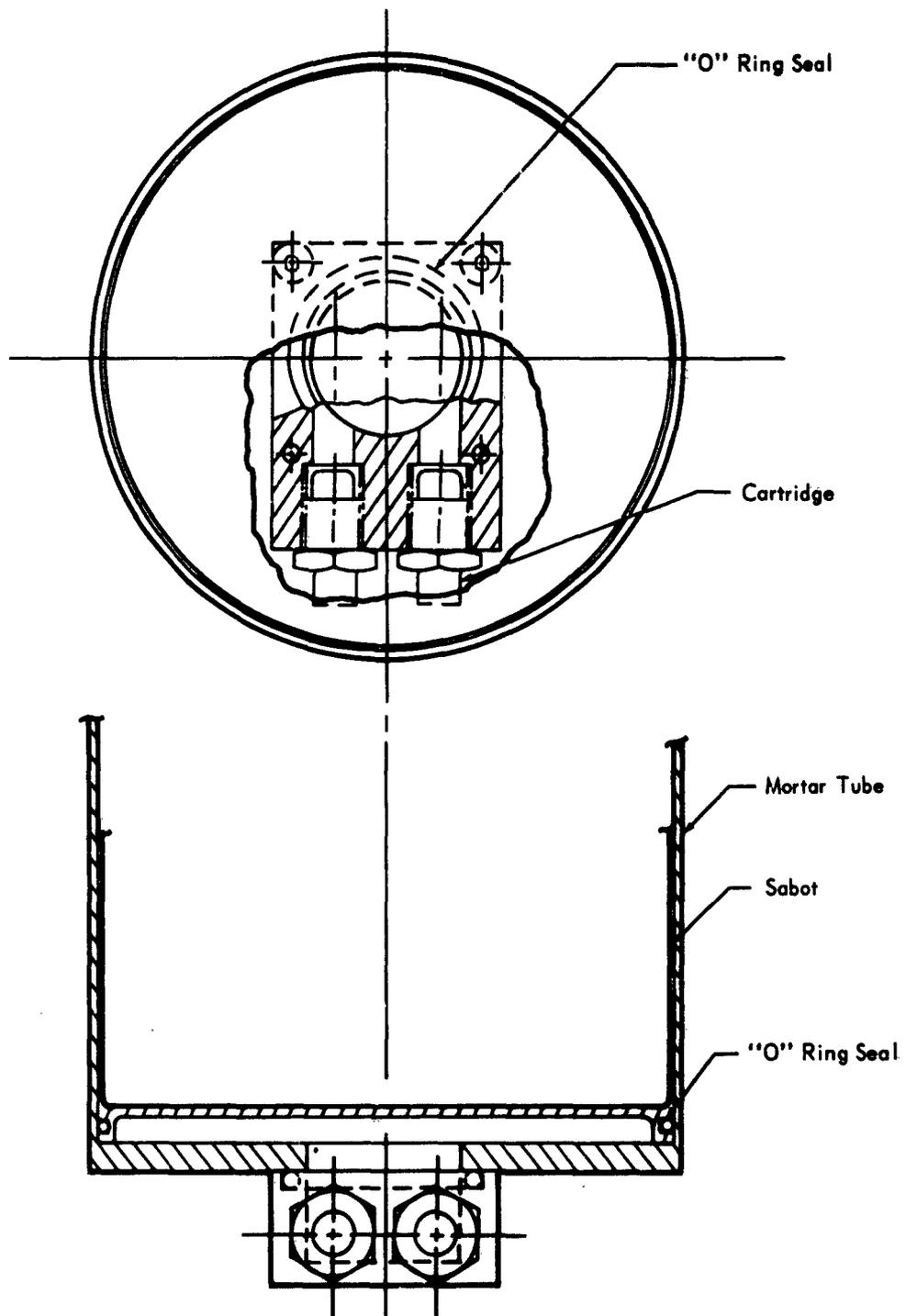
FIGURE 64   DROGUE CHUTE MORTAR

"O" Ring Seal

Cartridge

Mortar Tube

Sabot

"O" Ring Seal

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There are, of course, a number of ways to perform the repositioning and release operations. One of the more common methods consists of running the shroud line through a guillotine which would sever a loop in the line upon receipt of the proper stimulus. Such an approach, however, requires not only the guillotine but also some type of mechanical fastener through which the load is carried. In addition, the cutter would necessarily be void of sharp edges to prevent any damage to the shroud line that might result from oscillation of the capsule.

Explosive bolts, separation nuts, and MDC bolt popping also represent techniques by which release and/or full disconnect could be achieved. Unfortunately, most of these devices, by virtue of their mode of operation, either release shrapnel or flying parts. In addition, hot gases, often accompanied by explosive blast waves, would probably be released as a function of operating the device. All of these aspects are considered detrimental from the standpoint that either one or all could damage the shroud lines.

Considerable use has also been made of retractor and thruster-type devices to obtain either chute reposition or release. The advantage of such designs is primarily that the device itself not only performs the release function, but also acts as a load-carrying member. Also, the products of combustion are completely contained within the unit. The decision to use either a thruster or retractor-type unit is extremely difficult to make without detail knowledge of the structural configuration of the area in which the units are to be mounted. Consideration of the imposed loads are also of importance in selecting either a retractor or thruster.

(a) Design Criteria - Drogue Chute Reposition and Drogue and Main Chute Release Devices

The outline as presented below for operational design criteria is considered applicable to either a retractor or thruster-type disconnect. The items listed are intended to point out only major requirements that must be fulfilled when subjected to any combination of environments called out in the Appendix of this report. Release, as used herein, covers both reposition and disconnect-type functions.

o   The release device shall have sufficient strength to withstand all loads or combination of loads resulting from propellant gas pressure, environmental variations, and applied parachute loads.

o   The release device shall be capable of carrying the necessary ultimate load, whether applied in tension or shear at the maximum angle required as referenced to the centerline of the device.

o   The release device shall be capable of performing its necessary function of repositioning or disconnect under any combination of loads mentioned above, including minimum load condition.

o   The design of the release device shall be such that operation of the
        unit will not affect or otherwise damage or hinder the parachute nor
        its performance.

o   There shall be no shrapnel or flying parts associated with the opera-
        tion of the release device. In addition, all gases, whether products
        of combustion, explosion, or otherwise shall be completely contained
        within the device.

o   The release device shall be operated by a one-piece hermetically sealed,
        removable and replaceable cartridge. Design of the cartridge breech
        shall be such as to allow for initiation of the cartridge by either of
        two standard SMDC boosters.

o   The release device and its component cartridge shall be adequately
        sealed against all natural and induced environments. Life expectancy
        of the seals should be equivalent to or in excess of the power car-
        tridge portion of the unit.

(b) Parachute Release Design

Shown in Figure 65 is a typical thruster-type release device that can be used
for chute repositioning or complete disconnect. The particular design shown
is representative, with the exception of the SMDC initiation technique, of
that used on several existing vehicles. Upon initiation of either one or
both of the SMDC boosters, the firing pin will be physically deflected, thus
bringing about initiation of a percussion primer. The primer will, in turn,
bring about ignition of the cartridge. Force derived from the propellant gas
is then used to displace the plunger which brings about movement of the piston.
Following completion of both the plunger and piston stroke, the arm will
rotate about the hinge pin, thereby releasing the chute. The lead slug will
not only decelerate the piston, but also lock it in place, thus preventing
rebound. All residual air behind the piston will be dispelled through the
hole provided in the arm. This design principle was successfully used on
Project Mercury.

The drogue chute repositioning device shall be essentially of the same design
as discussed above; the only difference being that the unit is electrically
initiated. This could be achieved by merely replacing the SMDC with dual
redundant detonators of the type discussed in Section 2.4.1. Should one wish,
the SMDC receptacle, firing pin, and cartridge could all be replaced by two
electrically initiated cartridges. Although such a design would have a minor
weight advantage, the choice of redundant detonators located in the SMDC ports
is felt to be more consistent from an economical and logistic standpoint.

2.3.5.4 Riser Control - Drogue Chute Repositioning

One unique problem associated with repositioning the drogue chute is that of
protecting the drogue chute riser prior to repositioning, while permitting

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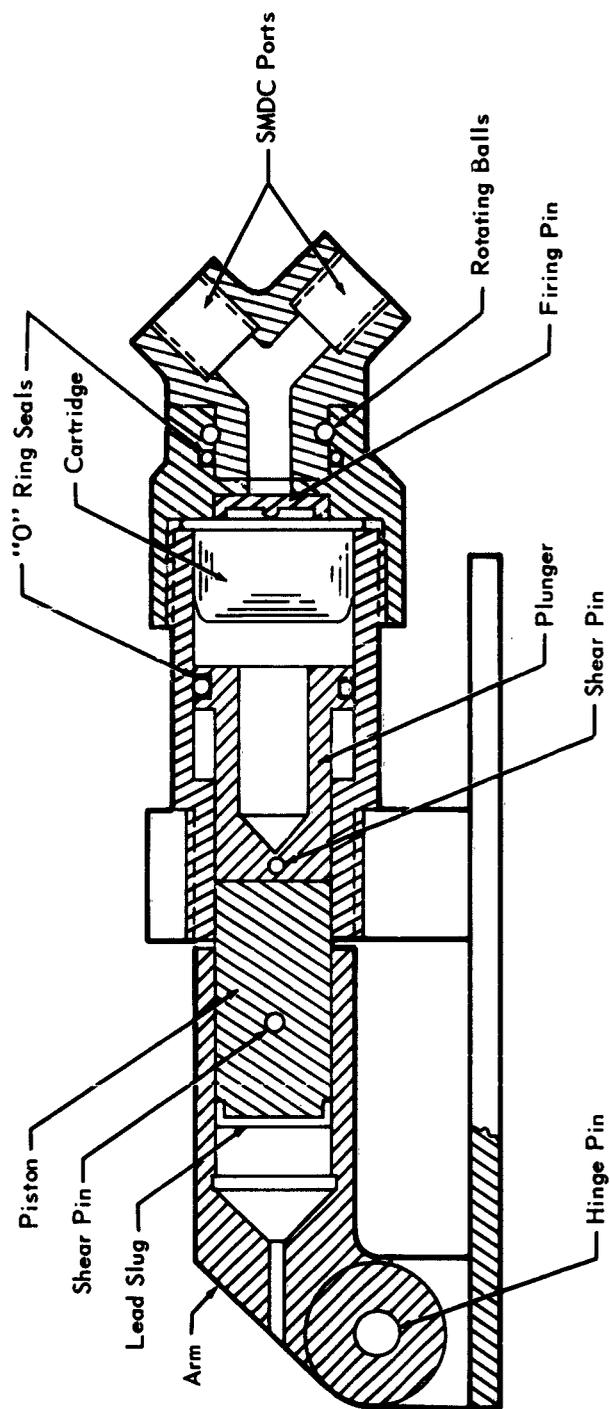
FIGURE 65 PARACHUTE REPOSITIONING AND RELEASE DEVICE

its free movement when repositioning. The drogue chute is deployed from the aft bulkhead of the escape capsule, and is initially suspended from that point. When repositioned, the chute must suspend the capsule from a point essentially over the center of gravi'y, forward of the windshield. Thus the riser must pass over the top of the cabin and over the windshield. Since the line must be thermally protected prior to deployment, it must be buried under the skin and insulated. The skin and insulation over the riser must be removed, or at least not impede the free deployment of the line, when repositioning occurs.

The selected method of accomplishing this is shown in Figure 66. A channel is provided along the top of the capsule, over the axis of the capsule. The line is housed in this channel, and the channel is packed with insulation. A thin "zip strip," made from the appropriate heat resistant or shingle material, is retained over the channel by lips on the heat shield on either side of, and fastening to, the channel framing members. The zip strip can be of sufficiently thin material that the force exerted on the drogue chute by aerodynamic drag is sufficient to rip out the zip strip without damaging the riser line.

2.3.5.5 Main Parachute Catapult

As was previously explained, in abort modes G/H there is not sufficient time for the full drogue chute sequencing for recovery system deployment. Therefore, the main parachute must be deployed directly upon initiation of the recovery system, with only sufficient delay for jettison of the windshield cover.

There are several methods by which this could be accomplished, including the use of a gun to eject a slug (as in a drogue gun), a mortar, such as is used for the drogue chute in this system, or a thruster or catapult-type device.

The use of a slug-firing gun is not satisfactory for a large parachute because of the heavy slug which would be required (weight penalty), and because of the severe loads which would be imposed at the instant the apex line comes taut, due to the inertia of the chute.

A mortar, which is highly efficient for a smaller chute, becomes impractical for this application because of the larger cannister required (which is a pressure vessel in a mortar, and thus becomes quite heavy). Also, the chute pack must be purely cylindrical, and this severely limits the flexibility in pack geometry which can otherwise be used in optimizing the layout of the components in the escape capsule.

A thruster, or catapulting-type device, appears to be the most desirable means of deployment for this application because it affords the flexibility in chute pack geometry which is desirable, and appears to give the lightest overall system. A true catapult, in which the moving member continues its motion and comes free from the fixed section, is not desirable, however, because there is too much danger that the hardware will damage or foul the parachute. The

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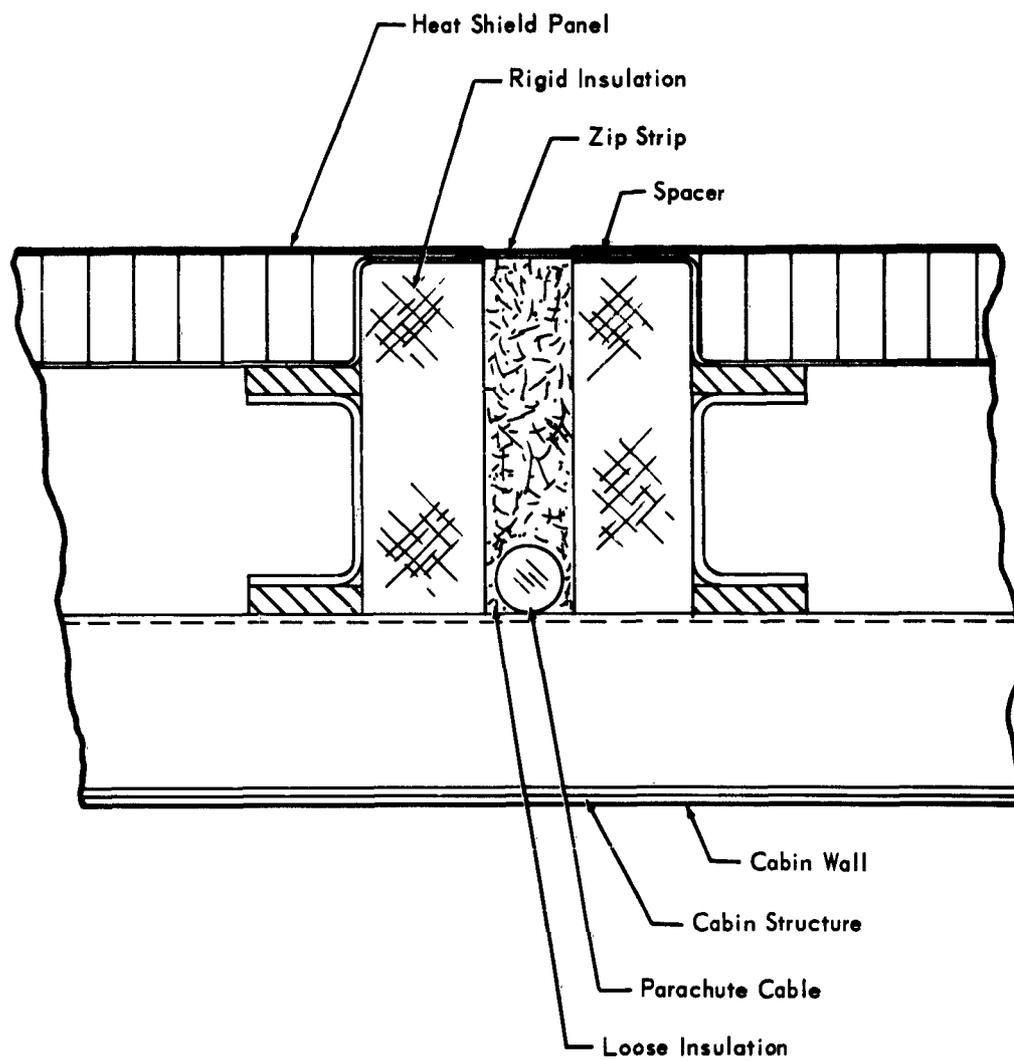
FIGURE 66   DROGUE CHUTE RISER PROTECTION

desired PAD will be a thruster to which the parachute basket is attached, and will incorporate a snubbing capability such that the moving section (piston) and the chute basket are decelerated and retained at the end of stroke.

Tests have established that a parachute of the size and weight required can be deployed satisfactorily at all speeds within the abort mode envelopes when ejected at 30-35 feet per second, and that a thruster stroke of approximately 8 inches will easily produce these velocities.

These data were used to establish the following design criteria.

(a) Design Criteria - Main Parachute Catapult

In addition to the environmental criteria discussed in the Appendix, the following performance criteria shall apply to the main parachute catapult:

o   The cartridge shall incorporate two electrical squibs, each of which is the dual-bridge, 1-watt, 1-amp type specified in Section 2.3.3.1 (f).

o   The cartridge must incorporate a nominal pyrotechnic delay of 0.3 second, to allow time for release and removal of the windshield cover.

o   For reliability, two complete pyrotechnic trains, from electrical igniter through delay column output charge, should be used.

o   The unit should be so designed that it can be installed from the outside of the capsule, and that access to the interior of the capsule is not required for installation or removal of the catapult.

o   The catapult shall incorporate a stroke-snubbing system so that the moving element plus the parachute basket is decelerated and retained at the end of its stroke, without damage to its mounting and without any breakage of its components.

o   If the propellant gases are vented at the end of the catapult stroke, the venting shall be controlled and the exhaust gases deflected so that no damage from heat or overpressure is imposed on surrounding structure and components.

(b) Selected Design

The design selected for the main parachute catapult is shown in Figure 67. The overall geometry is such that the cartridge can be installed into the catapult prior to its being bolted to the airframe, thus meeting the installation requirements. Two independent delay ignition trains are incorporated into a single cartridge head. Each train comprises a dual-bridge, 1-watt, 1-amp squib, a delay element, and an ignition relay charge. Both trains lead to a common ignition-prepressurization charge and the main propellant

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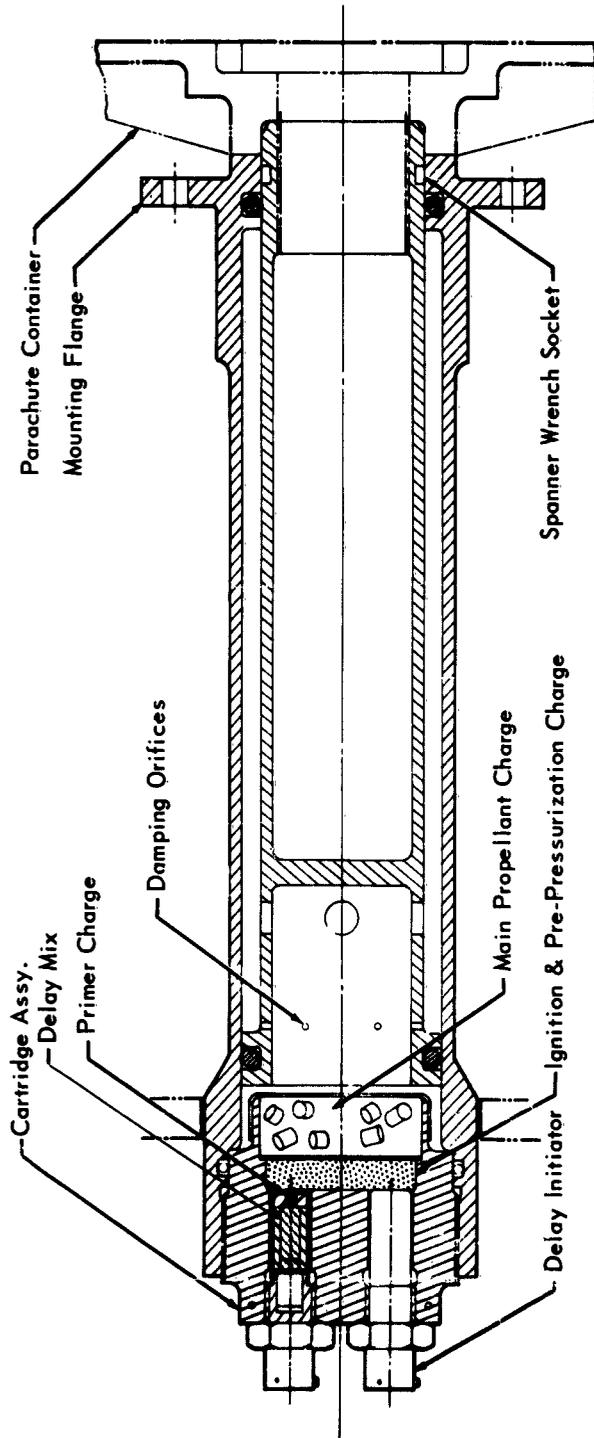
FIGURE 67 MAIN PARACHUTE CATAPULT

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charge. The ignition head is permanently assembled into the cartridge to eliminate tampering or accidental disruption of the cartridge seal.

The thruster is gas damped. During the early portion of the stroke, propellant gases flow through the ports in the "piston" wall and into the space between the piston and the cylinder wall. Toward the end of the stroke, these gases are compressed to a pressure higher than that of the chamber, and thus they start to reverse their direction of flow, moving back through the ports into the chamber. About one inch from the end of the stroke, the large ports cross the O-ring seal at the upstream end of the thruster, leaving only the small ports just above the piston head for this back-flow. The high pressure resulting serves to snub the motion of the unit. Mean·while, the large ports, having crossed the seal, permit a controlled venting of the chamber, thus reducing the snubbing forces required.

A thruster/catapult, quite similar in design to that described above, was developed for the F-111 escape capsule, and appears to work quite well, even when fired with an oversize cartridge. The parachute/basket assembly is of essentially the same weight, and an 8-inch stroke delivers the required velocity of 30 feet per second.

2.3.5.6 Apex Line Cutter

Normally the main parachute of the recovery system is deployed by releasing the drogue chute, whereby the apex line, which runs from the drogue chute risers to the apex of the main chute, extracts the main chute from its compartment and deploys it. However, in abort modes G/H for reasons and by means discussed previously, the main chute is deployed directly without the utilization of the drogue chute. Under these circumstances, it is necessary to sever the apex line, to avoid interference with the deployment of the main chute.

Conversely, when the drogue chute is used for main chute deployment, the apex line must remain intact and be free from mechanical interference so that deployment of the main chute is unhindered.

In order to meet the above conflicting requirements, a modified design of cutter is necessary. This modification requires that one side of the cutter body be hinged, so that the apex line can pull clear of the cutter when the drogue chute is used to deploy the main chute, and the cutter is not fired. While, as was previously discussed, such lines can be cut by use of a linear shaped charge as well as by a guillotine, the guillotine is considered to be far more desirable for this application.

(a) Design Criteria - Apex Line Cutter

The following operational requirements are considered to be optimum design criteria for the apex line guillotine:

o   Provisions shall be made in the design of the guillotine body for
    initiation by either of two electrically initiated cartridges, each
    of which is the dual bridgewire circuit and 1-amp/1-watt no-fire type
    as specified in Section 2.2.3.1 (f).

o   The design of the apex line guillotine assembly shall be such that when
    initiated by the proper electrical signal the apex line will be com-
    pletely severed, and must be free to slide out of the guillotine after
    firing.

o   The design of the release latch shall require sufficient opening force
    that no combination of dynamic loads (acceleration and vibration) will
    be sufficient to force the apex line out of its retained position prior
    to the proper time for extraction or cutter initiation.

o   The design of the release latch shall further permit the extraction of
    the apex line under controlled pull, said pull force being consistent
    with the operating requirements of the parachute system.

o   The design of the apex guillotine shall be such that no protrusions or
    sharp edges can prevent the extraction of or cause damage to the apex
    line when it is extracted by the drogue chute.

o   The design of the cartridges for the apex line guillotine shall be such
    that they may be removed from the guillotine assembly without the aid
    of special tools.

o   The design of the apex line guillotine assembly shall be such as to pro-
    vide satisfactory severance when the propellant charge is reduced to
    80 per cent of the specified load, and to operate without component
    failure when the load is increased to 120 per cent of the nominal charge
    weight.

(b) Selected Design

Figure 68 shows the selected design, which is identical to that presently in
use on Project Gemini. When the cartridges are fired, the expanding gases
pass through the drilled passages into an area behind the head of the guillo-
tine blade. As soon as sufficient pressure is reached, the blade severs the
shear pin retaining it and is driven forward, cutting through the apex line.
This disconnects the drogue chute from the main chute, and permits deploy-
ment of the main chute directly.

Under those abort modes utilizing the drogue chute for deployment of the main
chute, the release latch, which is spring loaded, is forced open to disengage
the apex line from the guillotine when the apex line is pulled against the
latch by tension from the drogue chute.
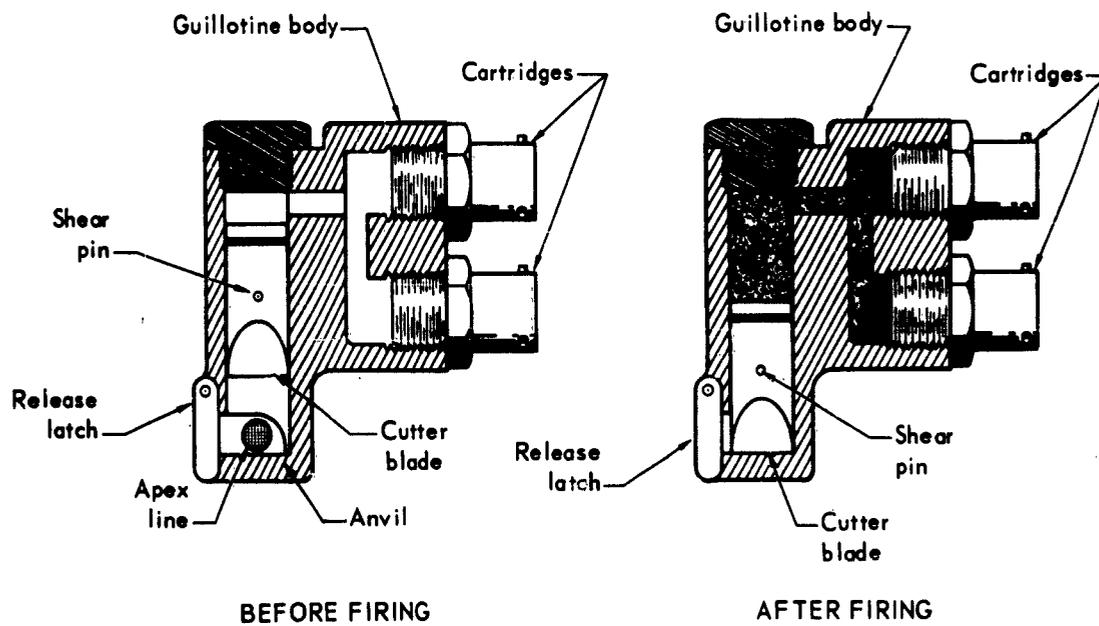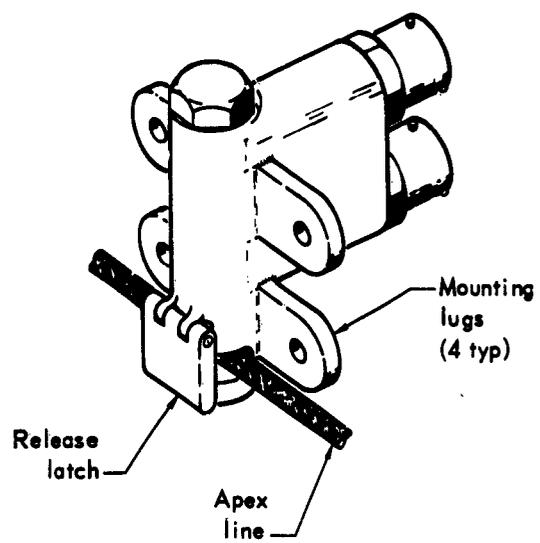
FIGURE 68 APEX LINE GUILLOTINE

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2.3.5.7 Reefing Line Cutter

A reefing line cutter can best be described as a small cable cutter. One major difference between the reefing line cutters and the larger cable cutters, however, is the use of a cylindrical cutting blade rather than the chisel point. This has been discussed in some detail in Section 2.3.1.2 covering the subject of cable cutters.

Though reefing line cutters can be designed for electrical initiation, they are most frequently built to be mechanically actuated. In the latter case the cutter is normally sewn into a pocket on the main chute. A lanyard is attached at one end to the sear of the mechanical firing mechanism and at the other end to some hard point in the aft bulkhead of the vehicle, so that as the main chute is expelled the mechanical firing device functions. Obviously with this type of arrangement a pyrotechnic delay must be incorporated between the percussion primer of the device and the propellant charge that operates the cutting blade; otherwise the main chute would be dereefed before being fully deployed.

(a) Design Criteria - Reefing Line Cutter

The following operational requirements are considered to be the optimum criteria for the reefing line cutter.

o   The design of the mechanical firing device shall be such that the pull force in conjunction with the stroke of the firing pin shall deliver the mean firing energy plus 5σ (standard deviation) of the primer used.

o   The design of the mechanical firing device shall not employ the use of precocked springs.

o   The direction of the pull force for operating the mechanical firing device shall be 0 to 30 degrees from the cutter axis.

o   The individual components of the reefing line cutter shall be designed such that they are capable of withstanding, if necessary as a function of its packing, the initial opening shock load of the chute.

o   The pyrotechnic time delay and its tolerance shall be selected to meet the performance requirements of the recovery subsystem.

o   The reefing line cutter shall be designed such that it cleanly severs lines of the required tensile strength compatible with the design parameters of the main chute.

o   The cutter blade shall be designed to include an O-ring seal in order to retain all propellant combustion products.

(b) Selected Design

The selected design for a mechanically actuated reefing line cutter is shown in Figure 69. It consists of four basic component parts which are the mechanical firing mechanism, the delay cartridge, the body, and the mounting bracket.

The firing mechanism is of a fundamental design commonly used in the ordnance field. After removal of the safety pin, the spring can be compressed by pulling on a lanyard attached to the withdrawal pin of the mechanism. By arrangement the balls cannot release the firing pin until the latter shoulders out; coincidentally, this in turn will have compressed the spring to near maximum. After release, the firing pin is driven forward by the energy from the compressed spring until it strikes and fires the primer.

To simplify the problem of providing moisture protection to the propellant charge and the pyrotechnic delay column, the cutter blade has been crimped to the output end of the delay cartridge. This also eliminates the need for a shear pin for the cutter blade.

No discussion will be made on the design of the delay column since this has been well covered in a preceding section. The design of the cutter blade has likewise been discussed before, and will not be further reviewed.

Primer

Delay Mix

Propellant

Cutter

First Fire

Firing Pin

Ball Lock Release

Safety Pin

Optional Firing
Head Design
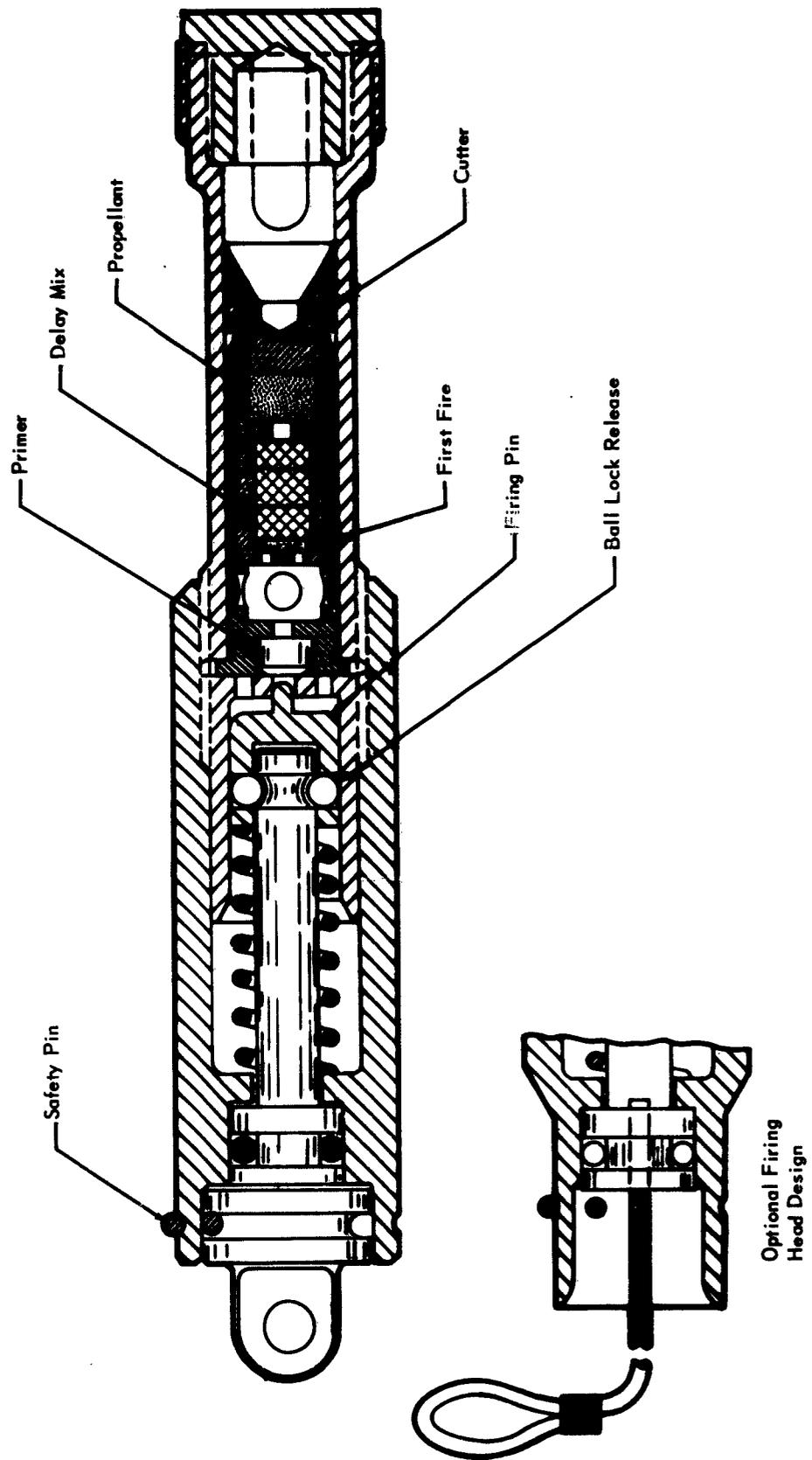
FIGURE 69   REEFING LINE CUTTER

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2.3.6 Impact Attenuation and Flotation Subsystems

2.3.6.1 General

The impact and flotation subsystems, although fulfilling entirely different
functions, are conceptually the same from both a system and component PAD stand-
point. As such, the particular schematic depicted in Figure 70 is applicable
to either of the two subsystems.

Upon receipt of the proper electrical signal, two separate and redundant initi-
ators will detonate parallel SMDC lines. As a result of this primary stimulus,
the compartment cover for each bag will be removed simultaneously with the oper-
ation of parallel explosive valves. All bags will be inflated by pressurized
nitrogen, the selection of which is discussed in detail in Part I. Single gas
bottles will be used to inflate both bags for either the flotation or im-
pact subsystem. With regard to the flotation bags, selection of the single gas
source was primarily made on the basis of the close proximity of the bags. The
pressurized cockpit will of course serve as flotation for the aft portion of
the crew escape module.

Since the impact bags are located both forward and aft, it became necessary to
consider two separate gas bottles as opposed to one centralized source. Very
little difference was found, however, between the two approaches with regard to
total system weight. It was, therefore, decided to use only one centrally lo-
cated gas source for the impact as well as the flotation subsystem. In arriving
at this decision, consideration was given to the fact that overall system re-
liability would be enhanced by removal of the valves associated with individual
gas bottles for each bag.

With one centralized gas source, the plumbing arrangement shall consist of one
line leading from the bottle to parallel explosive valves. From the valves, the
lines shall again tee into one, and thereafter again separate into two lines,
one for each bag. Although parallel explosive valves were selected, for reasons
of reliability, any computations that are made should account for the added num-
ber of joints which represent possible leak paths.

The basic initiators to be used for both the impact and flotation subsystems
have the same operating characteristics as described in Section 2.4.1 of this
report. The flotation and impact bag covers will be removed through the use of
flexible linear shaped charge. The choice of FLSC along with a proposed cover
design has already been discussed in Section 2.3.3.3. The only difference that
exists between the design shown in Figure 52 and the bag covers is the addition
of an elastomeric tube-type shield that is deployed with the bags for protection
against any sharp edges that might result from detonating the FLSC.

2.3.6.2 Valves

By definition, a valve is a device for stopping, starting, or controlling the
flow of a fluid or gas in a given system. When the valve is of the type gener-
ally categorized as propellant actuated, there are two means of providing the
activating stimulus - by propellant gas pressure or by explosive impulse. The
choice of which stimulus to use depends to a great degree upon the design and
size of the selected valve.

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Initiators

Impact or
Flotation
Bag Covers

Boosters (Dual)

Impact or
Flotation Bag
Inflation Valves
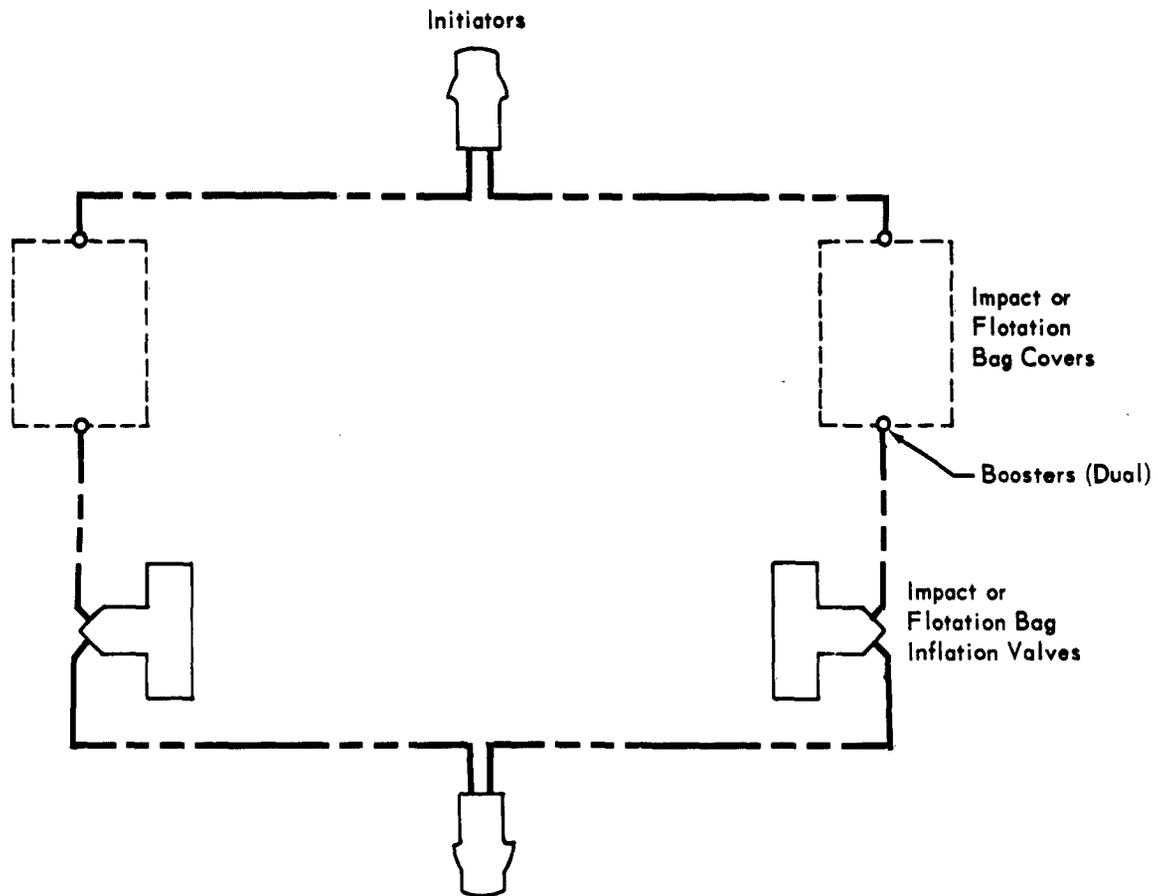
— — — — SMDC

— — — — — FLSC

FIGURE 70 IMPACT OR FLOTATION SUBSYSTEM

Essentially there are three basic design approaches available for operating the normally closed and the normally open valves plus a further approach applicable to valves in either condition. With the normally closed valve, one commonly used design requires the shearing out of a solid metal diaphragm, which actually forms an integral part of the valve body, in order to open the device (Figure 71). This particular design approach permits the valve to hold quite high pressures, in the order of at least 5000 psi, for long periods of time without any problems of leakage. A disadvantage to this design is the impossibility of reliably eliminating all fragmentation. Should contamination of the stream be a factor, then alternate approach must be used.

Another approach to the normally closed valve is to perforate the metal diaphragm by means of a very small shaped charge. This technique has the same disadvantage as the first approach in that it also produces some small fragmentation or contamination. It is also limited to the size of the hole produced by the charge, since one capable of providing a hole equal to the diaphragm sheared in Figure 71 would require substantial strengthening of the body housing.

A design approach for closing the normally open valve requires the firing of a tapered ram plug into the valve seat located in the outlet port. The propellant or explosive force must be sufficient to imbed the ram plug firmly in the valve seat so that essentially zero leakage is obtained at pressures up to as high as 10,000 psi.

A third design approach yields a valve capable of operating as a normally open, a normally closed, or a switching valve. It is shown in Figure 72. Its use as a normally open or normally closed valve is obvious from the illustration. As a switching valve, it can be used to divert flow from a single source to either of two outlet flow paths, or conversely, it can be used to switch from one source to another, feeding the same outlet. Its major disadvantage, aside from slightly greater weight, is the use of "O" rings as seals. This leads to a greater susceptibility to leakage than the integral bulkhead seal described above.

Since the design requirements of the subsystem require only normally closed valves, the design approach best felt to fulfill all requirements is that shown in Figure 71.

(a) Design Criteria - Explosive Valves

In addition to the environmental requirements outlined in the Appendix, the valve must meet certain operational requirements which include:

o   If the valve is powered by a propellant cartridge rather than by SMDC tips, the cartridge for actuating the valve shall be designed for ignition by means of a primer.

o   The design of the housing shall be such as to provide two threaded ports to accept two SMDC tips.

o   The design of the initiation system shall be such that the output from either or both SMDC tips will provide sufficient energy to fire the cartridge, if a cartridge is used. If the SMDC tip output powers the valve, the output from either or both SMDC tips shall be capable of operating the valve.

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SMDC Tip Receptacle

Swivel Head

Piston Retainer

Piston

Outlet Port

Solid Diaphragm

Inlet Port
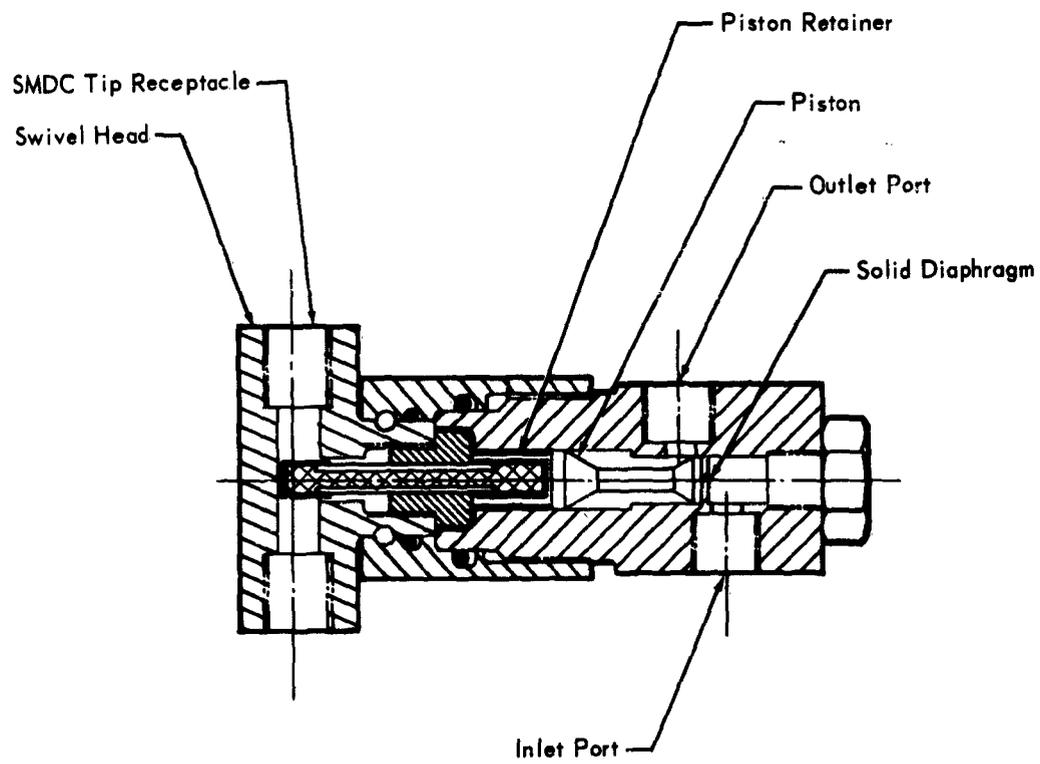
FIGURE 71 EXPLOSIVE VALVE – NORMALLY CLOSED

Swivel Head

Normally Open Inlet Port*

Normally Closed Inlet Port*

Lead Slug

Cartridge

Piston

Outlet Port
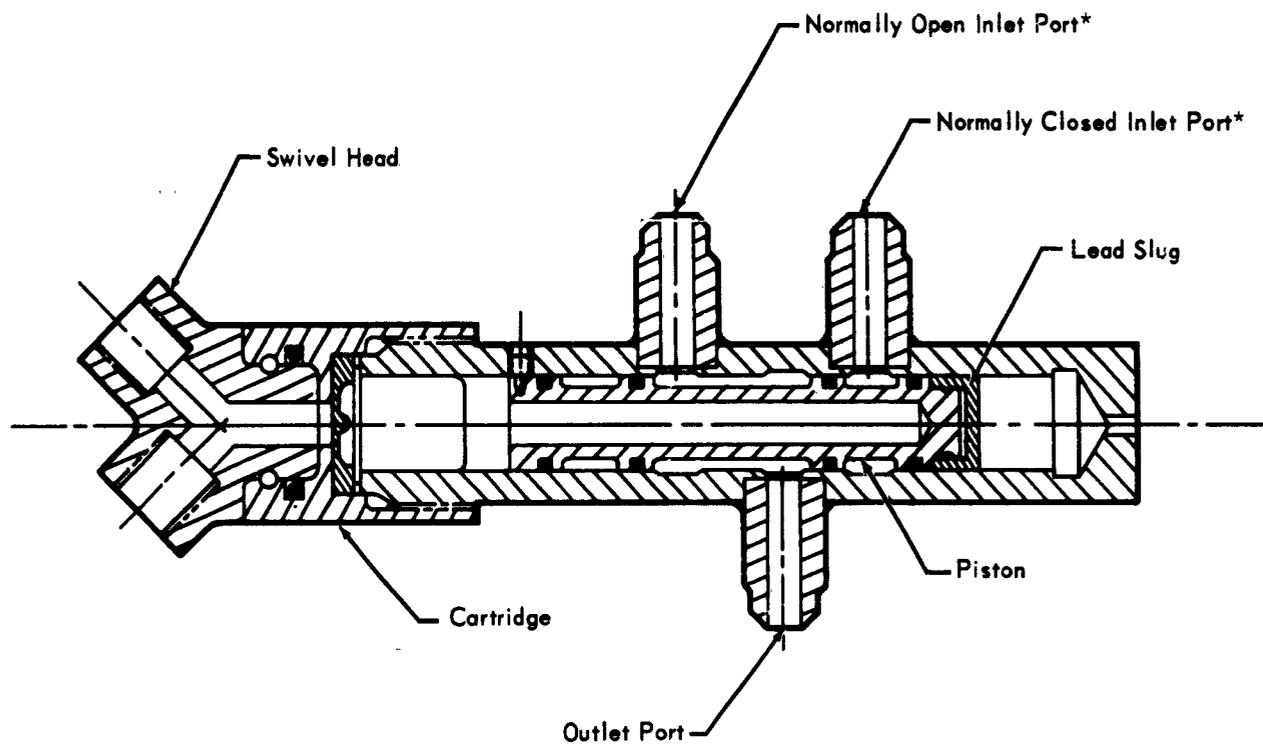
*Cap Unused Port

FIGURE 72   PROPELLANT ACTUATED VALVE — NORMALLY OPEN
OR NORMALLY CLOSED

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o   The valve shall be designed in such a manner that the mass flow rate
      is compatible with the overall system requirements in regard to bag
      inflation, etc.

o   The design of the valve shall be such that it has a zero leakage
      capability.

o   Any resulting fragmentation from the operation of the valve shall not
      affect the performance of the impact and flotation system.

(b) Selected Design

The selected design for the valves is shown in Figure 71. It consists
primarily of a valve block threaded to fit a swivel mounted T-junction
block. The T-junction block contains two standard SMDC threaded parts.
Initiation down either or both SMDC lines initiates the tip of the explo-
sive cartridge. This, in turn, initiates the output charge located behind
the piston head, which is driven forward, shearing out the metal diaphragm.
Loss of this diaphragm seal permits an uninterrupted flow of gas through
the valve block.

2.3.7 Landing Gear Subsystem

2.3.7.1 General

As pointed out in Part I, it is necessary to either jettison or retract
the nose landing gear during a mode G or H abort to offset an unfavorable
aerodynamic situation. An analysis of the two approaches indicated that
complete jettisoning of the gear would result in an appreciable shift in
the center of gravity of the vehicle. Considering the effect of the change
in center of gravity, it was determined that complete gear jettison would
create disturbing moments from rocket thrust misalignment, leading to potentially
dangerous instability. As a result, the decision was made to completely retract
the nose gear.

Retraction of the gear can be accomplished either pneumatically, hydraulically,
or with propellant gas. It was determined that normal extension and retraction
of the gear would be performed hydraulically. Although retraction is not a
flight requirement (due to the vertical launch mode), the ability to perform the
operation was incorporated to aid ground checkout. Since hydraulic retraction
was, therefore, available, attention was given to using the system for emergency
retraction. However, it was determined by comparison with similar systems that
minimum gear retraction time would be of the order of three to five seconds,
and thus not compatible with the overall abort system sequencing. A second
approach would be to supply an emergency backup pneumatic system to retract the
gear. It became immediately discernable that such a system would not only be
questionable with regard to operating time, but undoubtedly would weigh more
than a propellant gas system.

Retraction of the nose landing gear, regardless of whether it is a normal or
emergency operation, will be accomplished through the action of some type of
actuator. With this in mind, several design concepts were evolved, ranging from
separate actuators for both the normal and emergency mode to a small assisting
actuator for emergency conditions only. It finally was resolved that in order
to obtain the least possible weight, the actuator normally used to lower and
retract the gear would be fitted with an emergency retraction PAD. Considering
the problem even further, it was concluded that an abort condition could possibly
be brought about by a hydraulic failure resulting in an inability to lower the
gear. Although not necessarily part of the escape system, it was considered worth-
while to incorporate a second PAD within the actuator to lower the gear should
a failure exist within the normal hydraulic system.

Shown in Figure 73 is a schematic diagram of the nose landing gear subsystem.
As with most other subsystems discussed herein, SMDC has been used as the primary
stimulus to achieve a high degree of simultaneity and reduce the number of required
initiators. Should an emergency retraction be required, the two "up" initiators
would be fired simultaneously with the separation subsystem. This would bring about
initiation of a time delay cartridge in the door actuator and an instantaneous

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Up   Down   MDF Initiators

Door Actuator

T D Up

Dn

Landing Gear Actuator

Up

T D Dn

Up Lock Actuator

— — — — MDF

———— Electrical
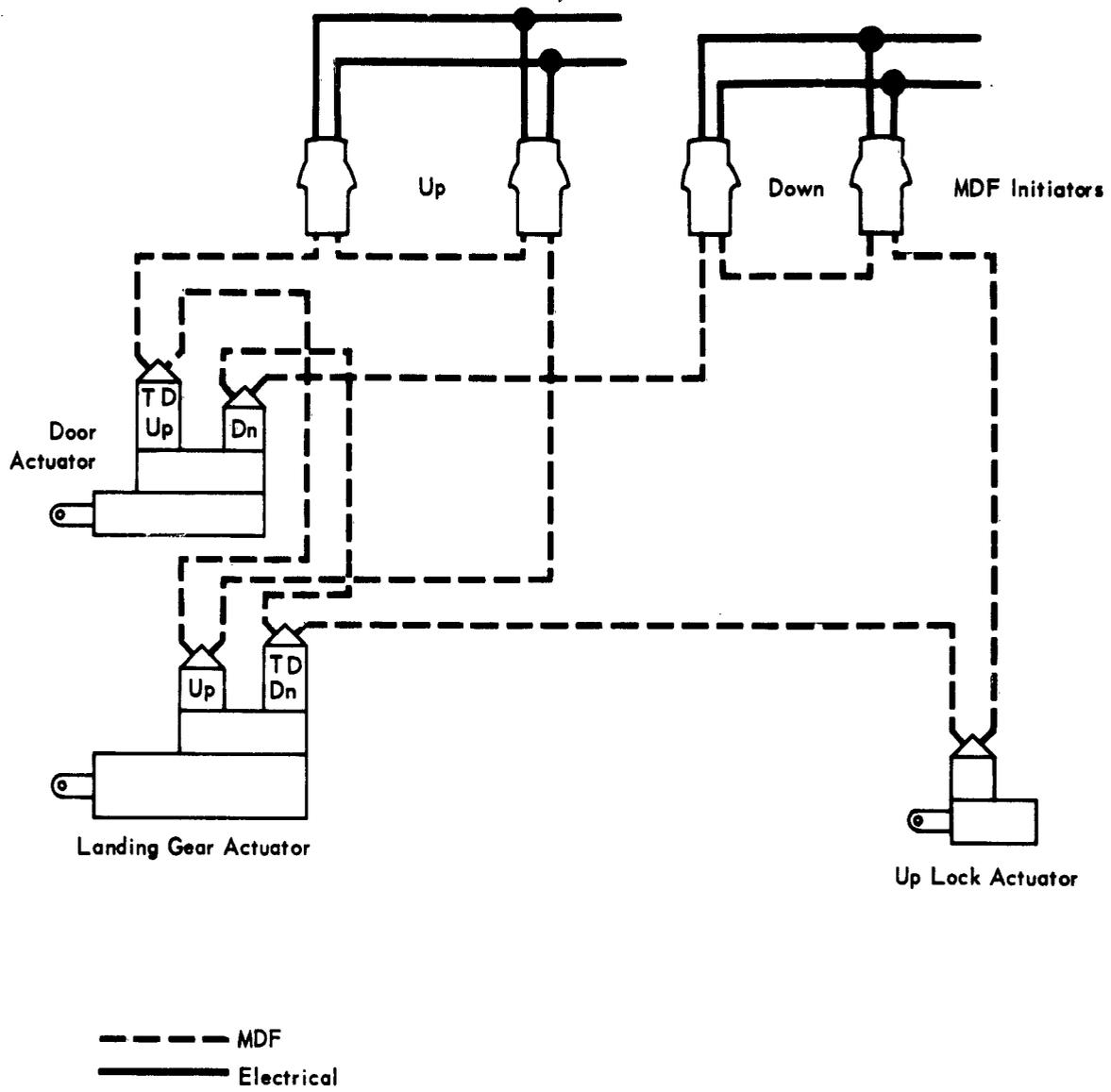
FIGURE 73   LANDING GEAR SUBSYSTEM

cartridge in the landing gear actuator. The time delay is intended to allow for retraction of the landing gear prior to operation of the door actuator. The two "down" initiators will be initiated only if some failure exists in the normal extension portion of the landing gear system. Firing of the "down" initiators will being about instantaneous operation of the door actuator and the up lock actuator. The SMDC stimulus also will initiate a time delay cartridge to operate the landing gear actuator. The length of the time delay is dependent upon the time necessary to operate the door and uplock actuators.

Design Criteria - Landing Gear Actuators

Since the design of both the door and landing gear actuators are essentially the same, the criteria outlined below is considered applicable to either unit. Where necessary, differentiation has been made between the two units. All of the listed requirements are intended to be fulfilled under any combination of the environments discussed in the Appendix.

o   The design of the actuator shall be such that in addition to its normal modes of operation it must be capable of performing either an emergency extension or retraction operation as the direct result of propellant gas pressure.

o   The actuator must be capable of either extending or retracting when subjected to any combination of the loads associated with a "G" or "H" mode of abort.

o   Operating time of the actuator, whether for retraction or extension, shall be maintained at a minimum, and be compatible with the system functions which either precede or follow actuator operation.

o   The design of the actuator shall be such as to accept the direct installation of individual cartridge initiators for emergency extension and retraction operation.

o   The design of the actuator shall be such that if an emergency extension is made, the unit is still capable of retracting through operation of the retraction cartridge.

o   The cartridge initiator used for emergency extension shall in no way contaminate, through its operation, the fluid system associated with the actuator.

o   The design of the actuator shall be such that complete retraction can be achieved through use only of the propellant gas derived from the retract initiator. Contamination of the actuator is allowable for a retraction operation.

o   All cartridges shall be designed as hermetically sealed one-piece items that can be installed and readily removed without the use of special tools.

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o   All time delays shall be contained within the hermetically sealed
         cartridges. Time delay tolerances must be compatible with the
         overall operating requirements of the actuators.

o   All cartridges shall contain percussion primers. Initiation of
         the cartridges shall be achieved as the result of the detonation
         of a standard SMDC booster.

Design Description

Shown in Figure 74 is the preliminary design for an actuator that will
fulfill the basic requirement listed above. As mentioned previously,
normal gear retraction is not a flight requirement but has been included
to supplement ground checkout and handling. Normal operation would be
achieved through the designated extend and retract ports in combination
with a selector valve.

In order to better explain the operation of the subject actuator, let it
first be assumed that the main piston is in the retracted position and a
particular failure has occurred which demands that the emergency system
be utilized to extend the landing gear. As such, the down initiators
would be fired, which, through the action of the SMDC, would bring about
simultaneous initiation of the up lock actuator, door actuator, and time
delay cartridge in the gear actuator. Section B-B of Figure 74 represents
the method by which the time delay cartridge is utilized in the landing
gear actuator. It should be noted that the entire cartridge extension
initiator is readily installed in the main actuator.

Upon firing of the cartridge, following burn-through of the pyrotechnic
delay train, propellant gas will begin to exert a load on the floating
piston of the emergency extension initiator. The propellant gas load
as transmitted by the floating piston will force the hydraulic fluid
contained within the extension initiator into the slide valve assembly.
The fluid, once in the valve assembly, will displace piston "B" to the
point that orifice No. 6 is open and orifices Nos. 4 and 5 are connected.
Once piston "B" has been properly displaced, the hydraulic fluid will
pass through orifice No. 6 and begin to stroke forward the main piston.
The displacement of the main piston will then force the hydraulic fluid
located on the rod end side of the piston back through the transfer
channel. After travelling the length of the transfer channel, the fluid
will pass through orifice No. 4, back through orifice No. 5 on into the
actuator bore and react against the head of the piston. It should be
noted that the extension operation just described is a completely closed-
loop cycle. As can be seen, the fluid contained within the extension
initiator accounts for the volumetric loss of piston rod as it travels
out of the cylinder. Consequently, the emergency extension operation
can be performed without the assistance of any fluid or hydraulic equip-
ment upstream from the actuator. Also of interest is the fact that the
floating piston/fluid reservoir concept prevents the system from becoming
contaminated by the propellant. As a result, it becomes only necessary

Floating Piston

SMDC Swivel Head

"O" Ring Seal

Hydraulic Fluid

B – B
EMERGENCY EXTENSION

Delay Cartridge

Rupture Disc

Firing Pin

Propellant Trap

Transfer Channel

A – A
EMERGENCY RETRACTION
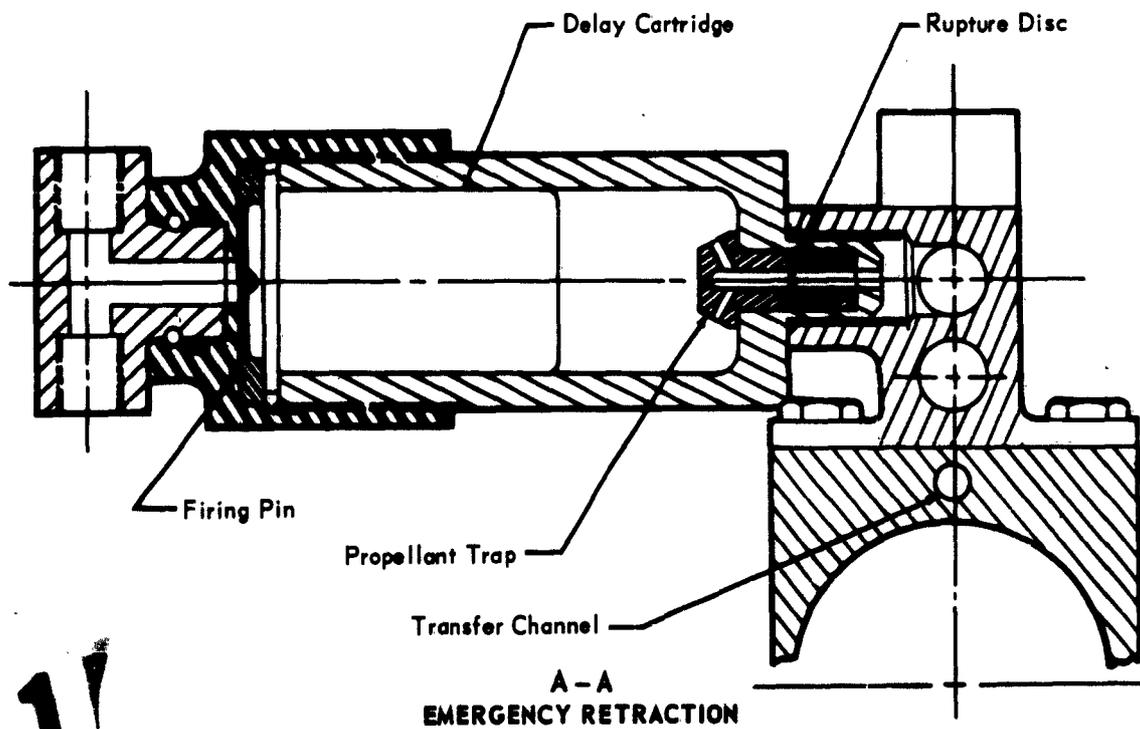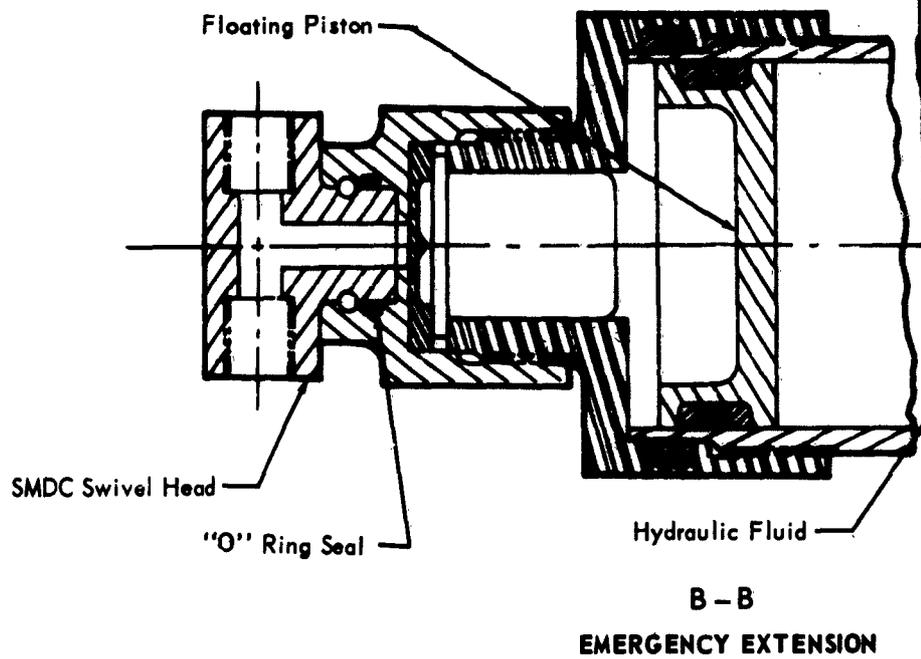
FIGURE 74   NOSE LANDING GEAR ACTUATOR

Floating Piston

Over

Extend P

To Selector Valve

Retract Port

ivel Head

"O" Ring Seal

Hydraulic Fluid

B – B
EMERGENCY EXTENSION

Slide Valve Assy.

A

Delay Cartridge

Rupture Disc

A

Retract

Extend

nnel

A – A
CY RETRACTION

LANDING GEAR ACTUATOR

/2/

To Selector Valve

Overboard Port

Extend Port

Retract Port

B

A

Slide Valve Assy.

Piston A

2

3

Piston B

4

5

6

A

B

Retract →
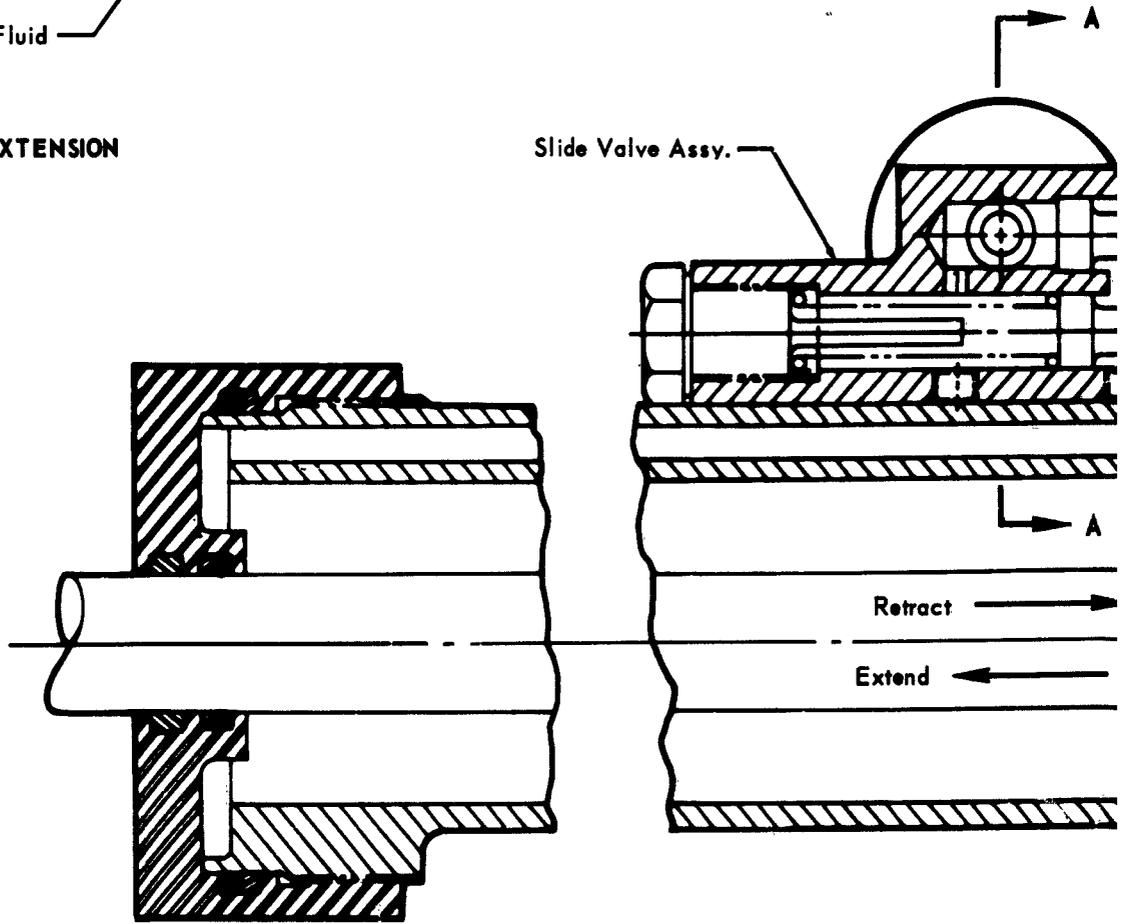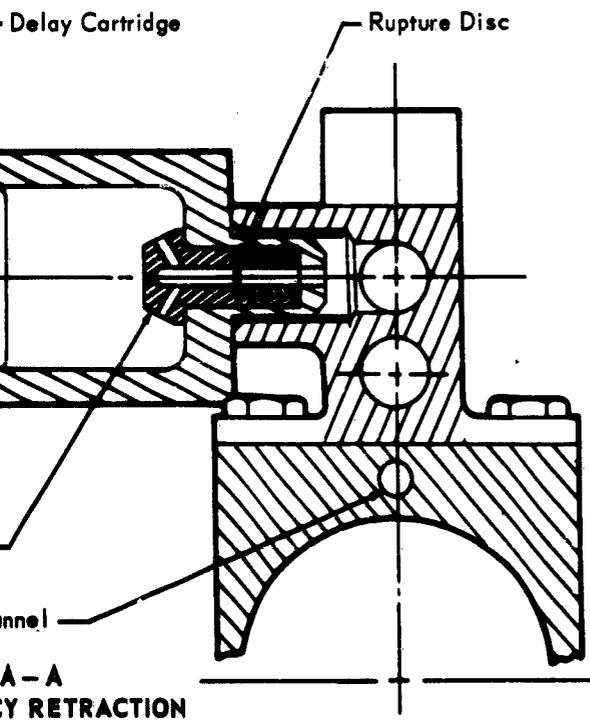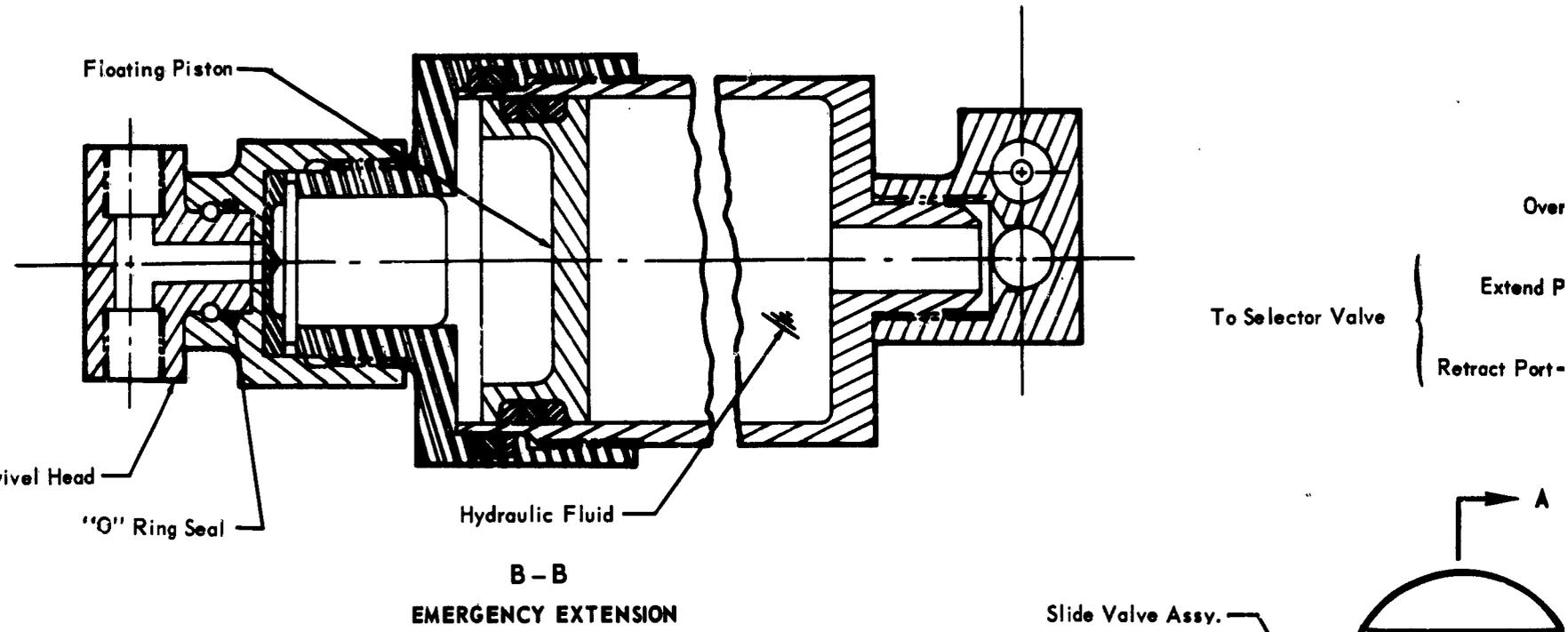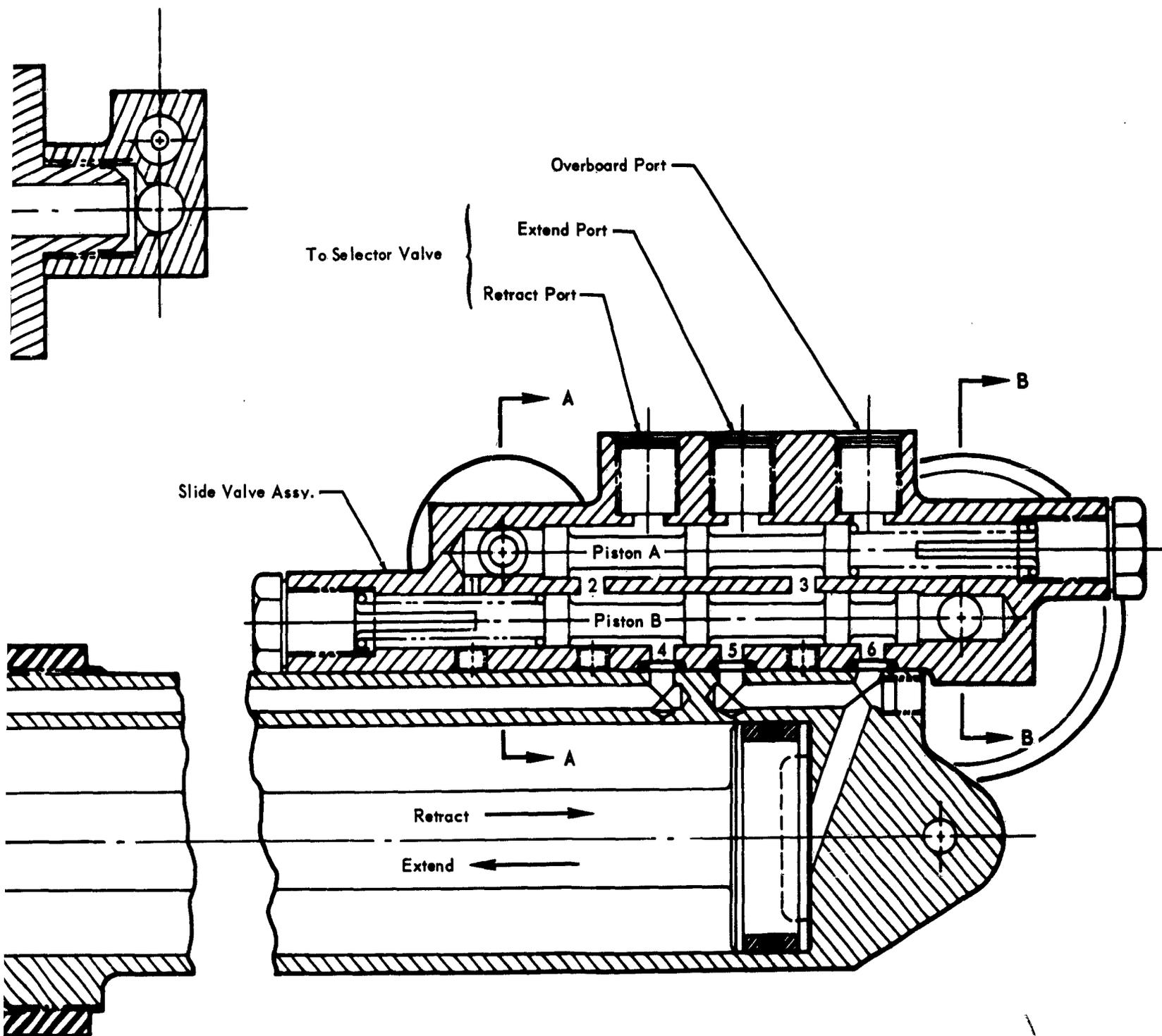
Extend ←

3

to replace the extension initiator once an emergency operation has been performed and the vehicle has safely landed.

Let it now be assumed that the condition which originally led to emergency extension creates an absolute abort situation. As such, the "up" initiator would be fired simultaneously with the separation subsystem. The SMDC stimulus would initiate the firing pin and fire a cartridge contained within the retraction initiator.

Once the cartridge has been fired, the propellant gas will shear the rupture disc and pass into the slide valve assembly. Since a complete abort is in process, there obviously is no concern with regard to contaminating the actuator. After entering the slide valve assembly, the propellant gas will pass through orifice No. 1 and displace piston "B" back to its original position. In addition piston "A" will be displaced to the point that orifice No. 2 is open only to the extent that the main retraction port is still closed relative to the flow of the propellant gas. After orifice No. 2 is open, the propellant gas will pass around piston "B" and enter the transfer channel through orifice No. 4. The gas will then react against the rod end side of the piston and bring about gear retraction. The fluid on the back side of the piston will be forced through orifice No. 6, around piston "B", out orifice No. 3, around piston "A", and then be dumped through the overboard port. Piston "A," through its original displacement, will prevent any of the fluid from entering the main extension port. If the gear has been lowered by normal hydraulic action, the retraction operation, should an abort situation develop, would be essentially the same as that just described. The only difference would be that piston "B" is in its original position.

2.3.7.2 Uplock Actuator

The design principle of the uplock actuator as depicted in Figure 75 is essentially the same as the door and gear actuators. Since the designs are conceptually the same, the design criteria previously outlined also is applicable to the uplock actuator. Should the cartridge in the uplock actuator be initiated, the gas pressure would react against the floating piston which in turn would force the hydraulic fluid through orifice No. 1. The fluid would then displace the slide valve assembly to the point that orifice No. 2 is open. After passing through orifice No. 2, the fluid would react against the rod end portion of the piston and thereby unlock the landing gear.

2.3.8 Miscellaneous

2.3.8.1 Devices Other than PAD

The following items, which are essential to the system but are not PAD, were not designed, nor were performance criteria developed in detail. Nevertheless, the comment below should be considered when the requirements are developed.

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Hydraulic Fluid

Cartridge

Swivel Head

Slide Valve Assy.

1

2

Hydraulic Port

A – A
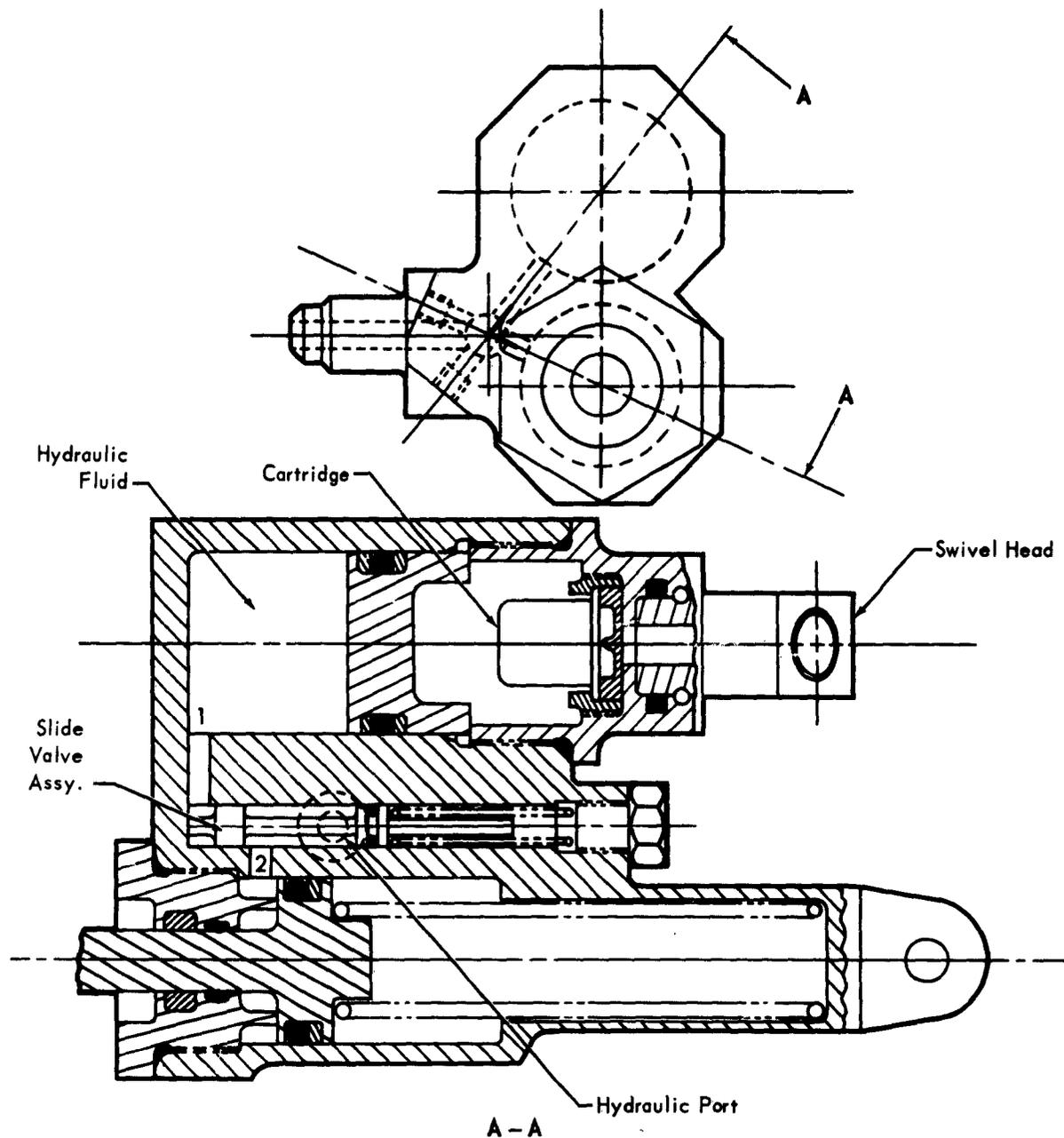
FIGURE 75 UPLOCK ACTUATOR

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(a) Intervalometer

Either tandem intervalometers or a single intervalometer having dual clock motor drive and dual contacts at each required time interval, should be used. In either case, an intervalometer is considered more accurate and more reliable than a series of pyrotechnic delay switches.

(b) Pressure Actuated Switch

As in the case of all other switches, redundancy is desirable in the switch which operates from the main chute catapult breech pressure. However, here extra caution must be taken to assure "fail-safe" operation. That is, in the case of those contacts which normally are closed, and open on actuation, the dual switches must be wired in series; conversely, those which close on functioning must be wired in parallel. Beyond this, the switch requirements, such as operating and proof pressures, should be determined during the catapult development.

(c) Inertia Switch

The inertia switch is used to initiate the flotation bags and the parachute release upon capsule landing impact. The required threshold acceleration, closing acceleration, and pulse time cannot be accurately determined at this time since they are closely related to the impact attenuation system characteristics. Nevertheless, the threshold level should be higher than any "g" level experienced during recovery, such as on parachute deployment, disreefing, etc. The closing acceleration should be low enough that it is always experienced on impact. The minimum actuating time can be determined roughly by calculating the time for a mass to decelerate from 30 feet/second to zero at the maximum tolerable "eyeballs down" deceleration rate. This gives a value of about .06 second at 15 g's. The shape of the deceleration pulse will influence this somewhat, so the above numbers should be used only as a first approximation.

In addition to the above, it is important that the "g-switch" be nonlatching. This is necessary so that, should the switch experience the above g levels prior to arming (as it will in an off-the-pad abort), it will be reset. This avoids the possibility of the chute's being released as soon as the impact switch is armed. The use of an arming switch late in the recovery sequence was dictated by this requirement.

(d) Barostats

The barostatic switches do not appear to have any unusual performance requirements. Initially, thought was given to the use of pyrotechnic locks which would retain these units in the "over-altitude" position until the escape system was initiated. This is done to prevent fatigue due to repeated cycling, which might be encountered in aircraft.

However, it is not conceivable that the glide vehicle will see sufficient reuse to enter the areas of fatigue failures. Thus, the use of locks, while of questionable merit, would represent one more element in the reliability network. This led to the decision to avoid their use in the subject application.

2.3.8.2 Inertia Reel

The flight dynamics of the complete glider as well as the crew escape module are such that it is considered apropos to incorporate an inertia lock reel into the astronaut's harness restraint system. Also, since it is not possible to completely predict the exact position of the astronaut for a mode "G" or "H" abort condition, the decision was made to extend the requirements of the basic inertia reel to also include a powered haulback capability.

The performance requirements for the powered inertia reel, as dictated by combined flight and escape dynamics, are not expected to be vastly different than those encountered in present day ejection seat systems. Since the reel will be located in the cockpit area, most likely on the back of the seat, the unit will not be subjected to any environmental extremes that are not compatible with human tolerance. Consequently, the power cartridge portion of the reel could be designed with present state-of-the-art materials.

Initiation of the cartridge and operation of the reel would undoubtedly be one of the first items accomplished in the escape sequence. It is expected that the operating time of the reel would be a maximum of 0.2 second for a 95 percentile man when subjected to a maximum opposing strap load of two "g." On a preliminary basis it would appear that the powered haul-back reel could be operated at the same time the landing gear is being retracted.

2.3.8.3 Flap Extenders

As discussed in Section 2.1.3.3, page 28, aerodynamic analysis has indicated the need for stabilizing flaps during Modes G/H abort. These flaps provide a trim point at a 10-degree angle of attack, thus eliminating a violent pitch-up which would otherwise occur at the time of capsule separation.

However, the location and design of these flaps were not determined, since they would be highly dependent upon the capsule construction. Therefore, it was not possible to provide a detailed design of the propellant actuated flap extenders needed to operate the flaps.

Basically, they would be similar to the windshield cover remover, Figure 60, page 119, in means of affording thermal protection, except that some form of locking provision at end of stroke would be required. Any of the conventional locking means, including an over-center bell-crank linkage could be used. If snubbing is required, the gas-damped snubbing design of the Main Parachute Catapult, Figure 67, page 135, is probably appropriate.

The flap extenders should be actuated from the landing gear subsystem, so that actuation is provided only in Modes G/H abort.

3. DELINEATION OF AREAS MERITING FUTURE RESEARCH AND DEVELOPMENT

3.1 General

One of the major goals of this study was to determine those areas of PAD technology in which research and development effort would be most useful. It was anticipated that those environments experienced by a glide re-entry vehicle would be quite severe, and thus would indicate a number of such areas.

It is, of course, true that due to the longer duration of re-entry, a lifting body vehicle experiences more severe heating conditions than a ballistic, or essentially zero lift, vehicle would. However, the temperatures experienced at the mold line are so high that any thought of placing propellants or explosives in direct contact with the skin is beyond the most optimistic stretch of the imagination. The unanimous opinion of the authors and those authorities consulted was that any material sufficiently stable to withstand these temperatures would not support a deflagratory or explosive decomposition.

Furthermore, the general opinion was that a practical limit for temperatures which any foreseeable family of explosives might be expected to withstand is in the neighborhood of 1000°F, and propellants somewhat less. Therefore, the use of PAD in an aerospace vehicle does not involve the question of whether thermal protection is required, but rather, how much is necessary. In the final analysis, many other items of equipment which must be used are more susceptible to temperature than the modern pyrotechnics, propellants, or explosives. For example, electronic gear, parachutes, pressurized gas tanks, and the man himself all must be provided a greater degree of protection than the PAD. In fact, even the structural members must be protected if an appreciable penalty in either weight or cost is to be avoided. Thus, except for the rare occasions where PAD will not be housed in the same environment as the aforementioned equipment, one is led to the conclusion that many other fields of technology must be advanced before PAD become the weak link, insofar as temperature is concerned.

The same is true of radiation. It is true that explosives and propellants deteriorate after sufficient exposure to various forms of nuclear radiation. However, the shielding afforded by the ordinary housings, such as vehicle skin, the PAD body, and a cartridge case, or similar sheathing for explosive materials, afford protection such that they are at least as stable as other materials, and many times less vulnerable than the man.

All other environments have been successfully met in other applications without significantly stretching the state-of-the-art, so there appears to be little promise of any appreciable payoff for research in these areas.

From the foregoing, and as the design study section of this report makes quite evident, a capsule-type escape system for aerospace vehicles, whether

of the ballistic or glide re-entry type, is fully within the capability
of current technology. Comparative studies will show that from the stand-
point of design limitations, the requirements for capsule escape systems
for high supersonic aircraft, rather than spacecraft, are pressing the
limits of the state-of-the-art. There are numerous reasons for this,
among which the following are outstanding.

o The aircraft systems, because of the much longer duration of
sustained heating, will make the thermal protection (insulation)
of all PAD more difficult if not impossible.

o The geometry of the various structurally integral escape capsules
considered for high Mach number aircraft is such that it is far
more likely that some PAD will be located at or near the skin.

o Thermal cycling, due to the more numerous flights per vehicle,
will be more severe, as will the accumulated time at high
temperature.

o Production and maintenance requirements will impose severe
restrictions on the designer, because of the differences in
technical ability of the personnel who will be used to service
the vehicle, and due to the differences in facilities available
for preflight and maintenance servicing. Thus the designs must
be easier to assemble and service and less subject to incorrect
assembly.

All of the above discussion is aimed at one general conclusion. For many
years to come, spacecraft requirements will be met by current technology,
and as these requirements become more severe, the technology will have
advanced by virtue of the needs for supersonic and hypersonic aircraft.
Any advantages gained for spacecraft applications, from research and
development efforts, will be secondary improvements rather than major
breakthroughs. Some of these may well be worth their cost; others
probably will not.

The major requirement for R & D in the coming years appears to center
around the development of adequate data on existing materials and designs.
One of the major problems encountered by the PAD designer is the lack of
data on performance, the effects of environments on performance, funda-
mental explosive evaluation techniques, and techniques for reliability
analyses on specific systems. In addition, a relatively large number of
PAD components exist of various size, shape, output, and stimulus
acceptance which would indicate a need of standardization where possible.
The following sections cover some of the more important areas where
additional R & D effort seems justified.

3.2 Characterization of Propellants and Explosives

One of the biggest handicaps with which the PAD designer is faced is the lack of adequate data characterizing the propellants and explosives he must use. While this is particularly true of the newer materials, it also applies to many of the materials which have been used for years, particularly where these are either proprietary items or where they were developed for different applications.

3.2.1 Propellants

Many of the PAD in current use, and many others still being designed, use the old standard gun propellants first developed before or during World War II. Considerable burning rate data are available on these propellants in the pressure range applicable to guns, but few have published data in the range of pressures most frequently used in PAD. Similarly, the data on new propellants are, in many cases, limited to a few scattered points at various temperatures, indicating that these data are developed only as they are needed for specific applications.

Many times the propellant used is of a commercial type, and there is no standard procurement specification from which the maximum lot-to-lot variation can be determined.

Another problem frequently encountered is the prediction of useful propellant life at specific temperatures or under conditions of thermal cycling. Until recently this has not created undue difficulty because most applications called for the same fixed operating range, namely -65°F to +160°F. However, for applications on the newer high-speed aircraft and spacecraft the temperatures to which various PAD are exposed are, in many cases, considerably higher. Furthermore, they will differ as a function of location so that no single temperature test will be useful in determining whether performance requirements are met.

Cookoff test data will not provide the required information, nor will the "salmon pink" or "red fume" tests used for double-base propellants, as described in Part I. A test determining deterioration, similar to the Taliani test, may be useable if ballistic performance can be correlated with the results. What appears to be really needed is a series of curves reflecting the deterioration of ballistic performance vs time at various temperatures, or vs the number of thermal cycles at some representative combination of temperatures and times.

3.2.2 Explosives

The characterization of explosives required to simplify the designer's task, as well as to increase the quality and reliability of his design, is quite similar to that needed for propellants. Many new explosives are being developed to withstand the more severe environments which will be encountered in aerospace applications. Some of these are being used in current PAD. However, in most cases the characteristics of the materials have had to be evaluated as the design and development progressed.

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The techniques presently accepted as standard for the industry for testing basic explosive parameters are inadequate for full utilization for PAD design. Plate dent, trauzel block, sand bomb and ballistic mortar tests do not provide the necessary information for the PAD engineer, especially in the area of miniaturization of components. PAD containing high explosives must be small with a minimum charge to reliably perform its design function. An example is the tip-to-tip cross-initiation of SMDC.

Extensive work has been performed on a limited number of explosives and sizes to understand the mechanism and ultimately to demonstrate reliability of explosive propagation across air gaps. The study revealed the mechanism to be one of metallic fragment impingement on the acceptor. Fragment pattern analysis, along with fragment velocity measurements, resulted in design criteria for thickness, type of material, shape of container, and explosive density. A theoretical reduction of all parameters resulted in a reliability approach and demonstration heretofore not found in the PAD industry. This approach should warrant further R & D study.

Another area of explosive utilization requiring additional investigation is the reduction in blast effects of such items as FLSC or MDC. This would include the areas of adjacent structure or components plus those components that do not see overpressure but are affected by shock transmitted through structure.

Similarly, the question of minimum propagation diameter, outgassing at elevated temperatures, and the influence of sheathing materials, are all requiring extensive examination. The above are perfectly understandable for new materials, but much effort of this type might be eliminated in the future if a pertinent series of tests could be devised to serve as guideposts in such areas. Some of these are straightforward; others, such as cross-initiation, might involve the development of empirical or theoretical relationships to relate the various parameters, but the cost of this basic research would be justified by the savings in time and money when actual hardware developments are necessary.

3.3 Theoretical Prediction of PAD Performance

A real need exists for simple digital computer programs to predict the ballistic performance of PAD under various types of loads. While previous work has been performed in this area, the programs have either been limited to specific types of PAD, too complex, or too limited in yielded data to justify their use for many design applications.

McDonnell has developed three Fortran programs to cover simple thrusters and gas and hydraulically damped thrusters acting against any combination of mass and resisting/assisting forces, whether fixed or variable, as a function of stroke. These programs will accommodate two propellants of differing burning characteristics. However, the programs have not yet been standardized to accept the same input data format. Their usefulness has been proved in several development programs, and the use of certain simplifying assumptions has been effective in holding machine time to a cost economically feasible even for small design projects.

However, additional work in this area would be desirable to standardize the input data format, and to cover a wider range of loading conditions, such as velocity-sensitive loads, velocity-position-sensitive loads, etc.

Further, a series of parametric studies could be devised to give design guidelines useful to those not having access to computers. Such data could be made part of a design handbook discussed in the "Conclusions", Section 3.7 of this report.

3.4 PAD Building Blocks

Design concepts presented in the design study section of the report have utilized, and shown the definite value of, the use of standardized components in the building of a system. Among the most obvious benefits to be derived are the following:

o Minimization of development cost and time - When, for example, a new PAD must be added to a system, the ignition or initiation components, having already been designed, need not be developed again. In many cases, where only the size of the propellant load differs from an existing cartridge, the cartridge can be qualified by similarity and the PAD need only be proved out functionally.

o Reduction in production costs - Many components could be mass produced, and then assembled in various combinations to form a large number of different devices. This, when compared with the cost of custom production of a myriad of different PAD, could lead not only to greatly reduced production costs, but also to vastly simplified logistics.

o Greater reliability and verification thereof - In order to hold the development and qualification costs of individual PAD to reasonable levels, the amount of development and qualification testing usually is held to a bare minimum. By the use of standard pyrotechnic components, the amount of qualification testing on each can be increased because it would be a one-time cost. In addition, the data derived from the more extensive use of the component would lead to far more accurate reliability data and higher confidence levels.

In Section 2.2.3, the use of standard igniters, MDC initiators, junction blocks, SMDC/primer initiator adapters, and delay elements, was discussed, and specific designs were presented. In Section 2.3.6.2, it was shown how the SMDC fittings can be used either to directly drive explosive valves or initiate a cartridge actuated valve. It is obvious that the same valve assemblies could be powered by electrically initiated detonators or propellant cartridges.

There is little need to discuss the above items further, but the following discussion will show how a standardized pyrotechnic switch assembly, for either an instantaneous or delayed switching action, can be obtained using the same initiating and power components.

There are several well-established and highly reliable families of pyrotechnic switches in existence, but none of those available offer an option on means of initiation, and none has a standard MS electrical connector for the switch terminal connections; nor do they have shielded-lead cable outputs. Nevertheless, where they can be mounted and connected within "black boxes," they represent an optimum design. In the application required for the escape system covered by this report, they were ideal, and therefore were selected.

But in other applications an isolated switch, remote from other electrical components or black boxes, may be needed to initiate some ordnance or other equipment. In this application, the flexibility of input and the standard connector output may be very desirable.

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An analysis of the various types of existing pyrotechnic switches, as well as the known reliability data on them, led to the conclusion that two design features are most desirable.

o   The driving piston should be positively locked in the "open" position prior to firing, and should lock in the "closed" position after firing.

o   The contacts should, once closed, maintain a closed position of such security that no shock or vibration experienced could induce contact chatter.

Figure 76 shows the design of a switch module which meets all the requirements mentioned above. The contact block has standard MS connector geometry, identical to those used in other areas of the electrical initiation system. The switch module can be combined with various combinations of instantaneous and delay initiators (Figures 33 and 76) to meet every possible initiation requirement. The actuating piston is locked "open" by a metal sabot which must be physically deformed before the switch will close; after actuation, this sabot acts as a locking sleeve which, by spring action, bites into the cylinder walls to retain the piston in its stroked position. The goldplated shorting element on the end of the piston will engage and lock into the mating connector pins in an identical fashion. Having a double locking provision, and only one moving part, there can be no possible contact chatter.

The possibility of standardizing other components undoubtedly exists. Those shown and discussed herein were selected primarily because they are in common demand, and because their need arose during this study or their desirability became apparent. Experience gained from some of these items undoubtedly would lead to the requirement for others.
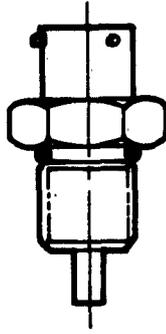
Standard SMDC Detonator
(1 Watt — 1 Amp)

SMDC to Switch
Adapter

Insulating Insert

Driving/Locking Sabot

Piston

Shorting Element
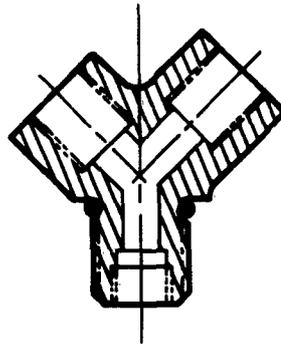
Connector
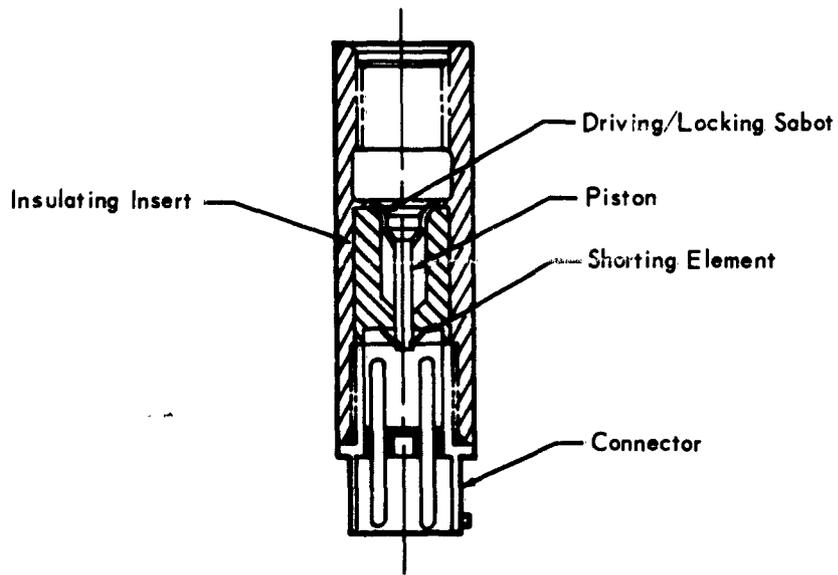
Switch Element

FIGURE 76 "BUILDING BLOCK" ELEMENTS FOR PYROTECHNIC SWITCHES

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3.5 Pyrotechnic Delay Train Improvements

Although pyrotechnic time delays can be fabricated to fulfill a wide range of applications, there are a number of problems associated with the producibility and the reproducibility from lot to lot. At present there is considerable secrecy surrounding each manufacturer's technique. The problem areas relative to manufacturing pyrotechnic time delays are described below.

In pyrotechnic delay elements the terminal charge at the end of the delay column appears to be a major factor towards the lack of reproducibility of burning time. It can be demonstrated that when a terminal charge is present at the end of a delay column, the burning time is significantly shorter than when the terminal charge is not present. More significant, however, is the increased dispersion of the burning times when the terminal charge is present. This "anticipatory effect" appears to be due to the permeation of hot gases ahead of the reaction front, said gases igniting the terminal charge. By the use of back venting and obturation at the output end of the delay, this anticipatory effect can be reduced greatly. Similarly, by placing a thin seal between the end of the delay column and the terminal charge, a slight reduction also can be effected. It is quite apparent, therefore, that this area of pyrotechnic delay mechanics merits much further study to resolve this problem.

Another area requiring systematic research is the determination of the best consolidation pressure for each delay composition and its varients. This pressure can probably be expected to vary to some extent between the burning extremes for each type of mix.

A further area open to study is the optimum size of each loading increment. A large number of small increments will provide a very uniform consolidation throughout the column length but it introduces a large number of increment interfaces which can cause a burning rate change across each interface. Where very few are involved, this may be of little effect on the overall accuracy of the delay, but increasing the interfaces would increase such changes until they became a significant factor. On the other hand, the converse is a problem. If the increment is made too large, then the burning rates vary with changes in the loading density. Much constructive work can be accomplished in a study of this problem area.

Of less obvious effect is the problem of the diameter of the delay column. Research programs could effectively establish the optimum diameter of the delay column for each type of delay composition and its variations. Delay column length has been recognized as another problem by some designers but many people either do not fully understand or know all the parameters required to bring a delay column from its first initiation to a state of burning rate equilibrium.

Excessive brisance of an initiating primer not only ignites the delay surface but may either cause fissuring of the column below the surface or it may drive hot incandescent particles slightly below the surface, all of which increase the time before equilibrium in the column is reached. The designer must realize that this initial instability, with relationship to burning rates, exists and it must be kept a small factor compared with the total burning time of the delay. It will be readily recognized that this will be more of a problem with a delay of short duration than that of a long one. Though much has been done in recent years in

designing for "soft" ignition, there is room for further work in this facet of delays.

One area of investigation which appears to offer an interesting and effective approach to pyrotechnic delays is the possibility of loading a relatively large diameter unit in a single increment. Then by a swaging process, a delay of the desired diameter and length could be produced. This, in turn, would produce a delay with a uniform loading pressure throughout the column length and without the increment interface problems normally encountered.

3.6 Development of Dual Thrust Escape/Retrograde Rocket Motors

As was discussed in Section 2.3.1.5.1, Part I, of this report, there are many advantages to the use of a jettisonable escape tower for abort from the launching pad and during early boost. Not only does the tower provide maximum allowable acceleration away from the booster, but also it provides higher stability during escape, and when supplemented by salvo-fired retro motors it yields a high, long abort trajectory, all at a minimum weight penalty.

This is achieved, however, at some cost penalty due to the expenditure of the rocket and tower on each flight. This cost could be saved if dual thrust rockets, providing high thrust for escape and low thrust for retrograde, were available.

Unless a thrust ratio of about 10:1 can be attained, there would be an appreciable compromise in one or both of the firing modes. If the escape thrust is reduced, the acceleration away from the booster and its potential fireball would be reduced; if the retrograde thrust is increased, a higher thrust attitude control system would be needed, thus leading not only to greater weight but also to higher propellant consumption.

Part of the ratio of thrust values can be obtained by salvo firing for escape and ripple firing for retrograde. Then, with three motors the thrust ratio between high and low levels need only be 3:1. This ratio is possible to achieve with the state-of-the-art. All that is necessary is to find a satisfactory method of varying the throat area of the nozzle such that the chamber pressure (and hence the burning rate) is such that the two desired thrust levels can be achieved. The following hypothetical rocket motor illustrates this concept.

Assume an escape motor which has a thrust level of 15,000 pounds and a burning time of one second. This gives a total impulse of 15,000 pounds-seconds. Three such motors, salvo-fired, would meet the requirements for the escape capsule under study herein. Next, assume that if the nozzle configuration is properly modified, this rocket will deliver approximately 5000 pounds.thrust for three seconds. If ripple-fired, these rockets will also give the desired retro thrust.

Assume the high thrust configuration operates at a chamber pressure of 1500 psi, and the propellant has the following characteristics:

r_b = 0.85 in./second

= .06 Lbs/In.^{3}

I_{sp} = 230 seconds

Then the mass flow rate required would be 65.25 pounds/second and the propellant web thickness would be 0.85 inch. The burning surface would be 1280 in.^{2}.

This same motor, burned at 300 psi chamber pressure, would have a propellant burning rate of 0.28 in./sec, and a burning time of three seconds. With a burning surface of 1280 in.^{2}, the mass flow rate would be 21.75 lb/sec. Allowing for a drop of I_{sp} to 210 seconds, due to the lower operating pressure, the thrust per motor would be 4560 pounds.

The throat area required for high pressure burning would be 6.35 in.^{2} or the throat diameter, 2.85 inches. At low pressure, a throat area of 10.14 in.^{2} would be required.

3.3.1 Sample Design

The design shown in Figure 77 illustrates one method by which the required variable nozzle can be obtained. Attached to the exit of the large area (retrograde) nozzle is a plate holding three smaller nozzles, the combined area of which equals the throat area of the high pressure nozzle, 6.35 in.^{2}.

The cluster of three nozzles was selected because it gives a shorter overall configuration while retaining an expansion ratio of 6:1. This configuration has been made and tested previously with excellent results.

The motor closures, or seals, are in the small nozzles. The nozzle plate is attached to the retro nozzle by a thin ring. Over the ring is an insulated, blast-absorbing housing which contains FLSC. When it is desired to separate the high-pressure nozzles, this charge is detonated, severing the attaching ring and allowing the propellant gas flow to impart an ejection velocity to the plate.

If the escape motor, or high-pressure, functioning is required, the motor is fired as shown. If the retro motor, or low-pressure functioning, is required, the igniter is fired with the plate in place. However, when the chamber pressure reaches a predetermined value (or after a short elapsed time, if desired), the FLSC is detonated to remove the plate. This operating sequence was selected so that only one nozzle closure is required, and so that reliable ignition of the low-pressure motor can be assured.

Pad Ab

Energy Absorber —

FLSC —

Seal —

Retro Nozzle —
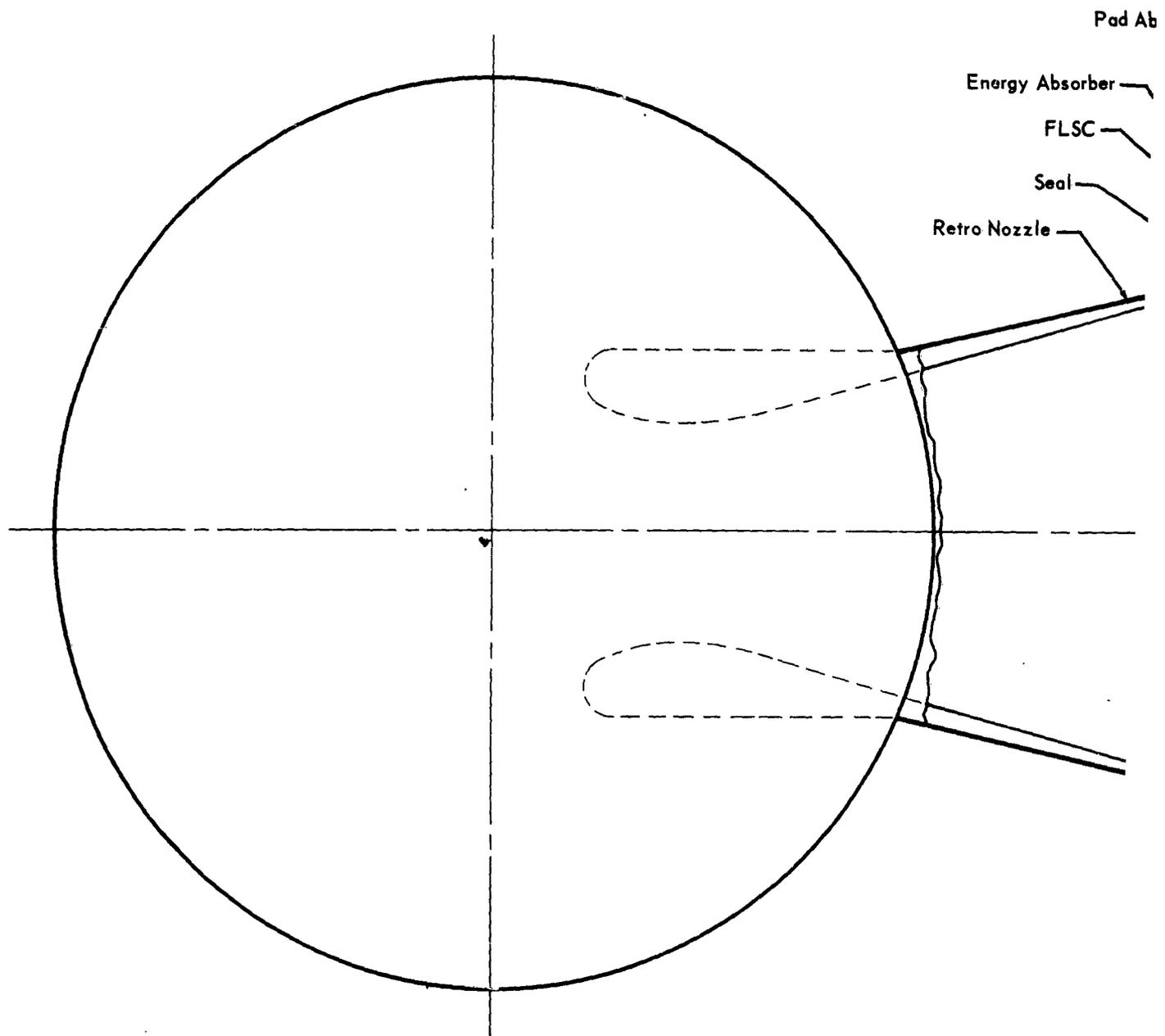
FIGURE 77 PAD ABORT/RETRO MOTOR

Pad Abort Nozzle

Energy Absorber

FLSC

Seal

Retro Nozzle
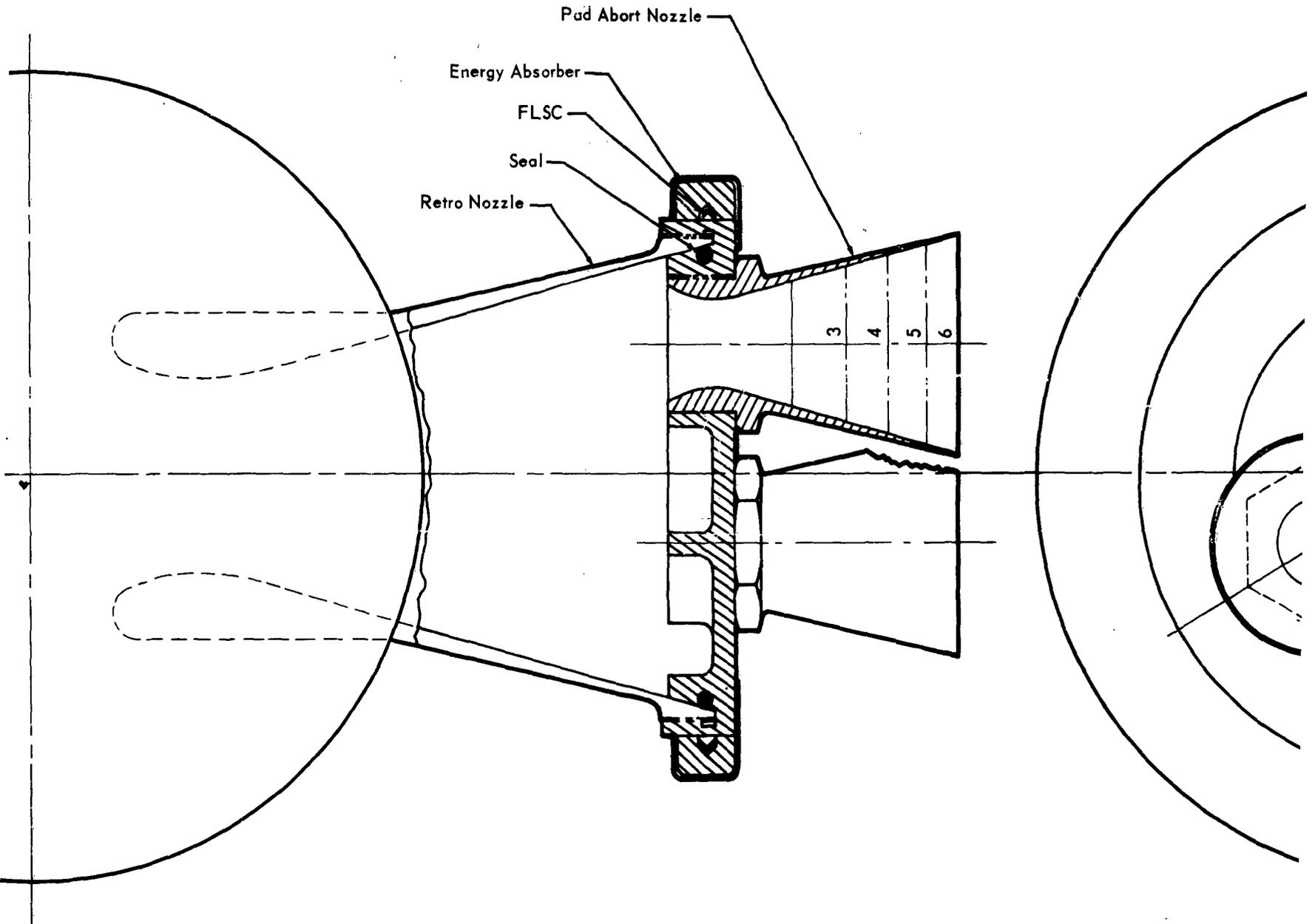
ABORT/RETRO MOTOR

2

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zle
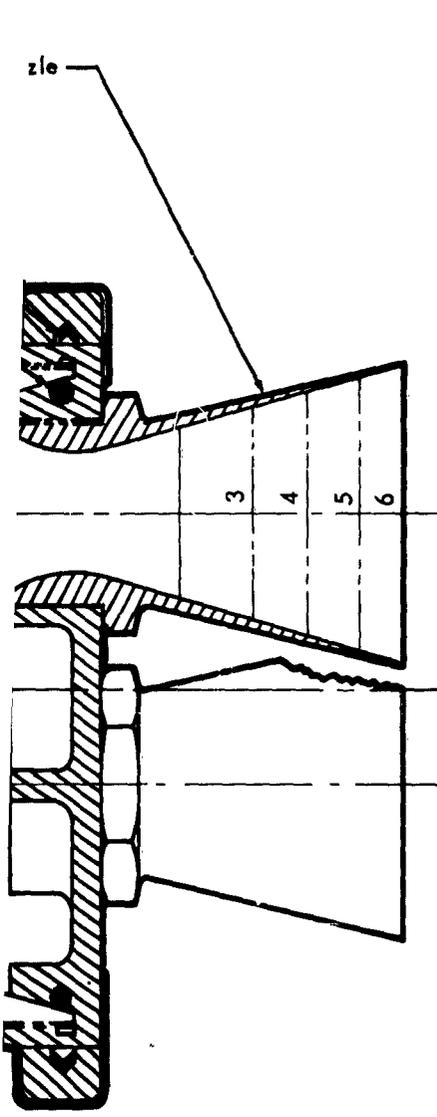
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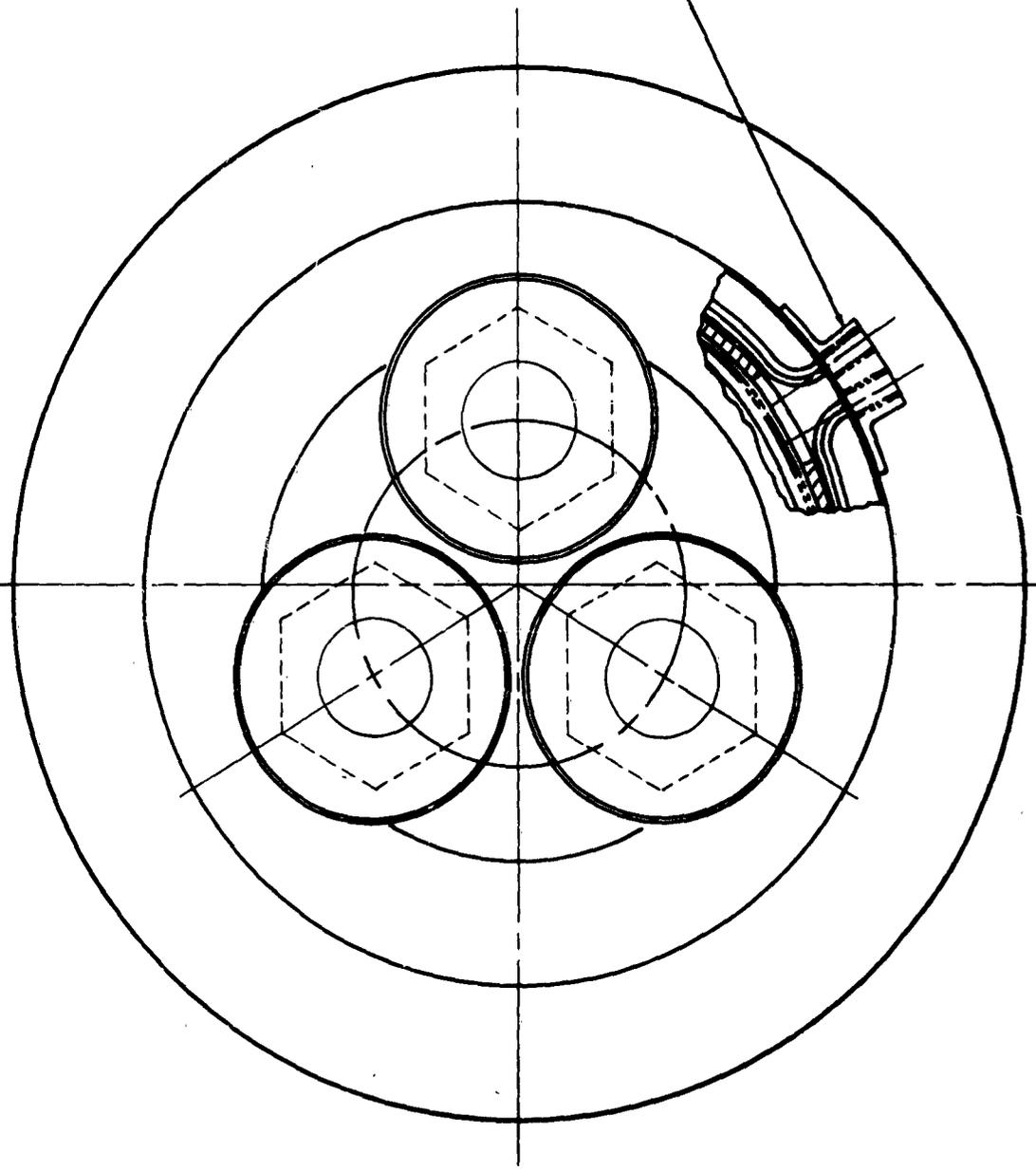
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3.7 Conclusions

The PAD required for aerospace vehicles of the type considered in this study are within the capability of current state-of-the-art. If the more recent developments in propellant and explosive compositions are considered, the environmental capabilities of PAD far exceed those of many other systems essential to the overall system.

The limits imposed by physical laws on the stability of explosives and propellants at high temperatures are such that no major breakthroughs will occur in this area; that is, these materials will never be able to withstand the skin temperatures incurred by a lifting body re-entry vehicle. Thus, insulation or thermal protection will always be necessary, and improvements in this area will only lead to second-order weight savings and then only if other systems achieve the same thermal capabilities as PAD.

R & D which is more urgently needed is the compilation of design data in a form useful to the PAD designer, so that he can more effectively use the materials already existing. Specific examples include the following:

- o   Development of useful theoretical and empirical equations which can be used with available explosive characteristics, such as detonation velocity, impetus, and sensitivity, to predict initiation characteristics of donor/receptor combinations.

- o   Development of new testing procedures to categorize explosives and propellants for such factors as degradation vs temperature/time, and degradation vs number of temperature cycles for various temperature-time combinations. One important determination in cycling is whether cumulative time at high temperature correlates with prolonged period at that temperature, etc.

- o   Standardization, to the fullest extent possible, of initiation and stimulus transfer techniques and components. For example, even where a multiplicity of connector bodies are required to avoid incorrect connection of a number of electrical squibs, cartridges, and detonators, a preferred means of accomplishing this would be by modification of the connector grooves and lands or locking pins, while identical internal arrangement and ignition components are used. Similarly, standard SMDC and CMDC and fittings, junctions, and terminal transducers (SMDC to primer stimulus transfers) should be used. This is in keeping with the concept of modular systems, or "pyrotechnic building blocks" discussed in Section 3.4.

- o   Design data for pyrotechnic delay trains, such as optimum diameter, loading increment L/D, etc., vs type and composition of mix; also methods of eliminating anticipatory effect.

- o   The generation of a pyrotechnic design manual, much more complete than anything previously published, would seem to be the ideal goal of future R & D effort.

In summary, we have just entered a phase of PAD which probably will be critical with regard to the immediate future utilization of these devices. Past applications have been relatively simple but the complexity of the systems has been vastly

increased in some of the most recent uses. Since complexity imposes more severe reliability demands, major effort should be placed upon thoroughly understanding existing materials to assure continued consideration and utilization of PAD as a preferred technique over competing schemes. It is more important that the immediate future be devoted to consolidating gains made in the state-of-the-art rather than further extending them.

APPENDIX

ENVIRONMENTAL DESIGN
CRITERIA

APPENDIX

Environmental Design Criteria

With the possible exceptions of the following two items, discussed herein, all design and construction, preproduction test, quality assurance provisions, and preparation for delivery requirements of specification MIL-C-25918(USAF) should apply.

"3.4.2 TEMPERATURE"

In most instances, this requirement should stand as written. However. it should be remembered that in certain types of PAD, particularly PAD incorporating pyrotechnic time delays, performance tolerances must be significantly larger in the wide temperature range (-65 to +200°F) than would be the case within narrower temperature limits (for example, -40 to +160°F). Some advances and new concepts have been under investigation, but at the best they are many times more costly, both to develop and produce. The added cost of attempting to meet close performance tolerances at the wide temperature range should be carefully weighed against the feasibility of providing closer temperature control over devices of this type. These remarks apply most significantly to the multitude of time-delay pyrotechnic switches which will be incorporated into and housed within the escape sequencing computer, and thus afforded the same thermal protection as the electronics. Conversely, the greater spread of delay times which would have to be allowed to meet the wider temperature limits could require greater time spans for sequencing and thus lead to a substantial weight and cost penalty for the escape and recovery system.

"3.4.11.3 ELECTRICAL FIRING MECHANISM"

This specification should be amended to conform to the use of 1 amp, 1 Watt no-fire electrical firing characteristics, as specified in AFMTC 80-2, which is mandatory for all new PAD used on vehicles launched from the Air Force Test Ranges. This specification is rapidly gaining acceptance throughout the industry, and has the advantage of requiring less electrical power aboard the vehicle while retaining excellent resistance to inadvertent firing. All electrically fired devices presented throughout this report have been based on the assumed 1 Watt, 1 amp units.

ADDITIONAL ENVIRONMENTAL CRITERIA

In addition to the environmental criteria specified in MIL-C-25918(USAF), the following are considered essential to the assurance of satisfactory performance in the subject application.

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PREPRODUCTION TESTS

40-Foot Drop Test - The PAD shall be capable of satisfactory exposure to the 40-foot drop test in accordance with MIL-D-21625, Paragraph 4.1.1.1. This states that the test shall be conducted in conformance with MIL-STD-302. Cartridges are to be mounted on a test vehicle affording the same degree of support as the device for which the cartridges are designed. Two cartridges are to be dropped in each of the following positions.

Nose up

Nose down

Horizontal

A new cartridge shall be used for each drop. It is not required that the cartridges be usable after the drop test, but no cartridges shall fire during the test. Cartridges must be safe to handle and dispose of after the test.

Inclusion of this test is necessary to provide a guide for safe handling of PAD devices.

Acceleration Test - PAD shall be subjected to the test determined to be the most stringent of those applicable to the devices. They shall be tested in each axis separately unless specified otherwise in the applicable PAD device specification.

(a) Launch - The devices shall operate while receiving acceleration along an axis parallel to the longitudinal spacecraft axis, increasing linearly from 1 g to 7.25 g in 333 seconds.

(b) Abort - The devices shall be subjected to the following accelerations:

11.6 g's for one second parallel to the Z axis
7.25 g's for one second in any direction.

(c) Re-entry - The devices shall be accelerated with a 1.5-g acceleration for thirty minutes along each of three mutually perpendicular major axes.

Acoustic Noise Test - The PAD shall be capable of satisfactory operation during or after exposure to acoustic noise for thirty minutes. The noise level shall have an overall sound pressure level of 155 decibels (relative to .0002 dynes/cm^2) with the following approximate distribution.

Octave Band cps	Sound Pressure Level decibels
37.5 - 150	141
150 - 300	146
300 - 1200	148
1200 - 9600	146

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The inclusion of this test is considered to be necessary to cover the environments found at launch, early boost, and re-entry.

Accelerated Aging Test - The PAD shall be capable of satisfactory operation after exposure to the storage test as outlined in MIL-D-21625, Paragraph 4.1.8, which states that the devices are to be placed in the temperature conditioning chamber in such a manner that the air can circulate freely about the devices. Temperature shall be maintained at 160°F. The following schedule provides for a total storage time of 24 days with periodic withdrawals for functional test.

Tuesday 0800	Place in +160°F Storage
Second Wednesday 0800	Remove six devices
Third Thursday 0800	Remove six devices
Fourth Friday 0800	Remove six devices

No attention is required outside of normal working hours except that necessary to insure that proper temperature is maintained. Devices shall be fired as soon as possible after removal from the high temperature. Instrumentation is desirable but not required for these shots.

This test is considered desirable because of its value in simulating long-term storage effects on the PAD.

Autoignition Test - The PAD shall not autoignite when subjected to a temperature of 250°F for ten minutes, except where otherwise noted. This test is essential in order to insure a safe margin above the highest anticipated operating temperature.

Oxygen Exposure Test - PAD shall be capable of satisfactory operation after two weeks (336 hours) exposure to 100 per cent oxygen at 5.5 psia.

Since many of the PAD devices may be exposed to high oxygen content within the spacecraft, this test is felt to be desirable.

Altitude Test - The PAD shall be capable of satisfactory operation after two weeks' exposure to a pressure level equal to 820,000 feet, and shall be capable of satisfactory operation during or after exposure to a pressure level equal to altitudes from sea level to 820,000 feet.

This test is considered to be essential since it simulates the pressure environment that PAD devices might have to experience.

ACCEPTANCE TEST

Cartridge Leak Test (100 per cent) - Each cartridge shall be subjected to a dry leak test to establish the quality of hermetic seals. Measured leakage shall not exceed 1×10^{-6} standard cc/second of helium at a pressure differential of 0.1 atmosphere. Rejection of individual cartridges prior to any

other conditioning shall not be cause for rejection of a production lot. Leakage after conditioning for other acceptance tests shall be cause for rejection of the cartridge lot.

While immersion leak tests are acceptable for preproduction tests and destructive sampling tests, they are not suitable for cartridges to be subsequently used in service, since an undetected failure enhances the change of operational malfunction. This test is intended to replace other leak tests as a 100 per cent acceptance test procedure.

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13. ABSTRACT

This report describes the results of the third and final phase of a study related to the design of PAD (Propellant Actuated Devices) for use in a separable crew escape module applicable to a lift/glide re-entry vehicle. Based on results of Phases I and II, preliminary designs have been established for each PAD as a function of component performance criteria. Prime consideration was given to successful abort at any point during the mission profile. It was found possible throughout the entire Phase III effort to evolve component designs for each PAD function without exceeding to any great extent the present state-of-the-art. As a result, the areas mentioned for future research and development are generally concerned with characterization of the more promising new explosives and propellants, and the presentation of several concepts, which, if developed, would offer secondary improvements in the overall system weight, reliability, or cost.

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14. KEY WORDS	LINK A		LINK B	
	ROLE	WT	ROLE	WT
1. Propellant Actuated Devices				
2. Crew Escape				
3. Aerospace Vehicles				

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